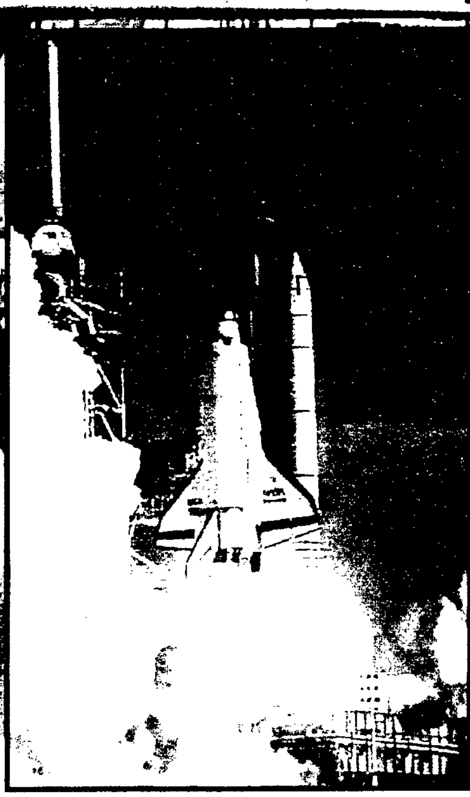
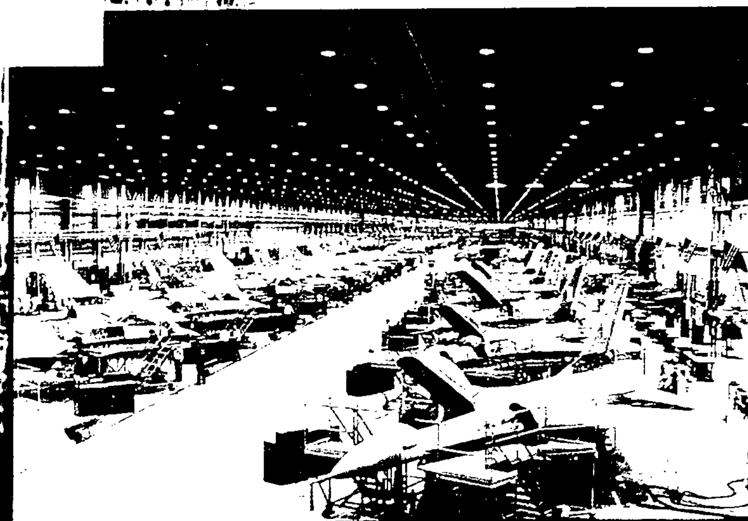
Air Force Research Laboratory

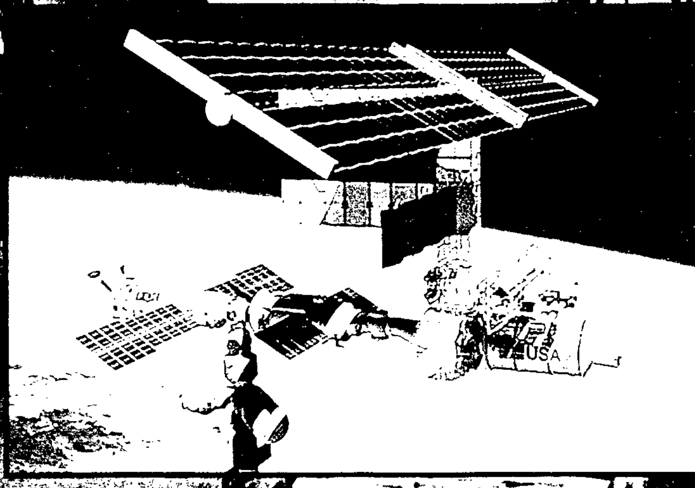
# Manufacturing Technology

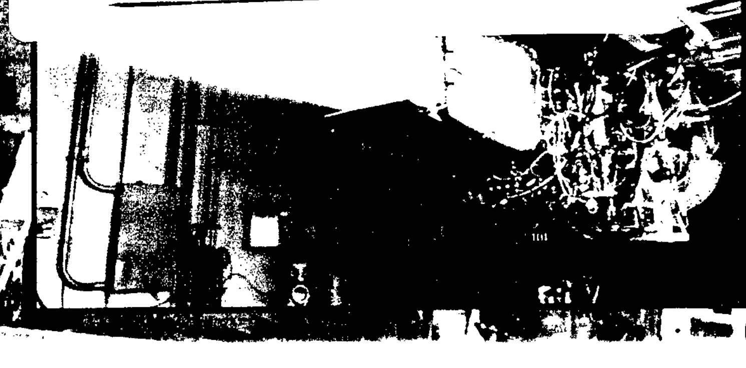




# 1998 Project Book

## A Digest of the Air Force's ManTech Program





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The 1998 edition of the Manufacturing Technology "Project Book" summarizes projects in progress or completed since publication of the "1996-97 Project Book Update." It is a "living" document, with the specific purpose of promoting the transfer of technology which has been developed through investments in the defense industrial base. It is organized in such a way as to provide information needed to decide whether the technology described will be useful.

Each project is summarized on a single page containing an explanation of why the project was needed, what approach was used to accomplish the effort, the benefits expected to be realized, the project's current status, the name of the project engineer, and the performing contractor.

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# Introduction

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Each project is summarized on a single page containing an explanation of why the project was needed, what approach was used to accomplish the effort, the benefits expected to be realized, the project's current status, the name of the project engineer, and the performing contractor.

For current information on a variety of division activities, visit the **Manufacturing Technology Division's homepage** at: http://www.wl.wpafb.af.mil/mtx

In all cases, for additional information, submit a request specifying which programs are of interest and what information is needed to:


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# Advanced Modular Factory

**Cooperative Agreement Number: F33615-96-2-5113 ALOG Number: 1488**

## Statement of Need

Adaptation and implementation of best industrial practices is a centerpiece of the transformation of the defense industrial base. The adoption of lean production principles, as characterized first by the Japanese automotive industry, is showing immense benefits for previously inflexible, nearly-captive military producers in the U.S. industrial complex.

This lean implementation program is to focus on the demonstration of a particular factory operational concept popularized in a few commercial production enterprises. Those commercial producers have seen vastly improved flexibility and quality coupled with reduced costs and cycle time; similar benefits for the production of defense product are therefore the objective of this program, as is a collection of a cogent business case for the changes wrought.

## Approach

Hughes Missile Systems Company (HMSC) will utilize as a baseline the current missile business practices and manufacturing processes in use at their Tucson, Arizona facility. HMSC will develop, implement, validate, and measure alternative business practices as well as new manufacturing processes identified by the Lean Aircraft Initiative (LAI). A transferable methodology will be developed for evolving military unique operations into common lean business practices and manufacturing processes. Validated lean practices and processes will be transferred into a demonstration missile product line and the before-and-after performance will be measured along with well defined metrics. The process methodology will be documented so that the experience and lessons learned can be transferred to other product lines and aerospace companies.

## Benefits

Hughes Missile Systems Company will apply modular factory concepts to the flow of materials through its missile factory in Tucson. Similar implementations in commercial industry have seen vast improvements in cost and cycle time. Specific benefits for AMRAAM will be tracked over the course of this effort.

## Status

*Active*
*Start date: September 1996*
*End date: November 1998*

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# Agile Infrastructure for Manufacturing Systems Pilot

**Cooperative Agreement Number: F33615-95-2-5520 ALOG Number: 1349**

## Statement of Need

Agility in manufacturing is viewed as the ability to thrive in an environment of continuous and often unanticipated change through an enterprise geared toward "reconfigurable everything." Agility addresses the business enterprise world, including: business practices; the culture of management and employees; financial control and operations; relationships of the customer, assembler, and supplier; manufacturing process integration with design information systems to support decision making information systems for empowering workers; accounting systems to reflect operations; and education and training.

This initiative includes the "lean manufacturing" emphasis on the streamlined, efficient use of resources and the minimization of waste. It also embraces the best commercial quality management practices of customer focus, an empowered and knowledgeable workforce, teamwork, communication, and continuous improvement. It also includes integrated product/ process development and flexible manufacturing capabilities; requires flexible management structures with commitment to societal and environmental concerns; and requires a networked infrastructure capable of supporting "virtual corporations" and other agile organizations that can respond to rapidly changing market demands.

## Approach

This program will demonstrate and evaluate the advanced design, manufacturing, and business transaction processes that enable agility within an organization. The program focuses on the technical and cultural tools necessary to bring agile manufacturing to the aerospace industry. The program will provide: a working virtual corporation prototype; a proven, scalable support architecture; a template for agile business transactions over the Internet; procedures and metrics for certifying and categorizing agile suppliers; validated metrics for managing an agile virtual corporation; and a migration business plan for the resulting products.

## Benefits

This program will enable companies with different, complementary core capabilities to come together as virtual corporations and will remove roadblocks that hinder rapid and efficient teaming arrangements in an electronic commerce environment.

## Status

*Active*
*Start date: January 1995*
*End date: January 1998*

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AIP

Advanced Industrial Practices

# C-17 Lean Aircraft Initiative

**Contract Number: F33657-95-D-2026 ALOG Number: 1506**

## Statement of Need

Surges in production over the last half century have made the US military aircraft industry a mass production system, but one which overlays what is essentially a craft work force building aero-structures with mostly non-interchangeable parts. Although highly skilled at fitting, few aerospace workers were empowered to improve their processes to solve production problems or to respond to changing conditions. As in Henry Ford's mass production system, aircraft manufacturing processes were owned by remotely located engineers. A number of historical barriers and business practices have impeded the adoption of improved production practices like those pioneered by Japanese auto builders. Cold War emphasis on performance and procurement policies (such as annual buys and pricing based on costs) offered little incentive to improve factory flow or to put the worker back in charge of his work. Risk adversity was a competitive advantage. Investing in lean principles was difficult under these conditions. The Lean Aircraft Initiative has identified flow optimization as an enabling practice for the production enterprise. Benchmarking data from the LAI suggests that a modular organization of the factory is a powerful means of optimizing flow. Derivation and demonstration of the modular factory concept for the defense production environment requires consideration of business practice changes, infrastructure improvements, and identification of the barriers and disincentives to its implementation.

## Approach

The modular factory is a reorganization of production resources into semiautonomous modules, each with total responsibility and authority for a set of processes, adding value to the product to ensure success for the entire enterprise. Typically, modules are arranged within the factory around the assembly sequence, with the next higher assembly operation as the customer. The module is characterized by: empowerment of workers and teams, emphasis on training for skill interchangeability, dedicated capital equipment, aggressive inventory reduction, focus on work flow velocity, shop floor density to reduce transportation time, and gain-sharing incentives for employees.

McDonnell Douglas will demonstrate the benefits of lean production in order to incentivize change, and to reduce the cost of the C-17 aircraft. Specifically, cost reduction and quality improvements will be sought for C-17 components through adaptation and implementation of observed best practices. By sharing lean production methods and results through the LAI consortium, change may be incentivized at other aerospace companies, as well as at MDA facilities.

## Benefits

The C-17 Lean Aircraft Initiative team has established stretch goals for the project which include:

- 50 percent reduction in defects per unit
- 50 percent reduction in inventory
- 50 percent reduction in assembly cycle time
- 15 percent reduction in C-17 Cargo Ramp direct labor (fabrication and/or assembly)
- 30 percent reduction in C-17 Main Landing Gear Pod direct labor

## Status

*Active*
*Start date: October 1995*
*End date: October 1998*

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# Design Information Retrieval Using Geometric Content

**Contract Number: F33615-96-C-5615 ALOG Number: 1478**

## Statement of Need

The need for a software tool to query a large, potentially distributed database of design information is crucial for many different applications like collaborative design environments, parts/supplier selection, design for reuse, product database management and so on. Most of the efforts in this area allow for database search using textual attributes. This project is developing an Internet-aware geometric information analysis and retrieval technology that allows a user to search for CAD models with similar geometric content.

## Approach

The contractor will use the following approach:

1) Develop a mechanism to accept computer-aided design (CAD) product models in several formats.

2) Develop an internal representation scheme for 3-D models.

3) Determine a suitable set of features to abstract the geometric information for feature comparison and indexing.

4) Develop a visual query mechanism for user interface to the software meta indexing scheme.

5) Develop a software mechanism to perform queries and updates remotely over the internet.

6) Integrate proposed software with commercial CAD system.

7) Transition technology to suitable groups or institutions.

## Benefits

The benefit for the technology developed under this project is giving the engineer the ability to search for CAD models and associated design information in a platform and vendor independent way over the Internet. This allows:

- increasing the value of feature-based design and manufacturing paradigm by incorporating feature-based retrieval
- savings in cost and time by reducing the chances of design duplication through reuse of designs created at a different place and time
- reducing the supplier chain redundancy by locating parts of similar geometry and or functionality

Two long-term benefits can be foreseen:

- Currently, STEP is a standard for design information exchange. Since the Virage technology extracts a proxy representation of CAD models in a system independent way, it will augment STEP standards for content-based information retrieval
- The effort, integrated with textual information retrieval, will lead to a standard API for design information retrieval

## Status

*Active*
*Start date: April 1996*
*End date: April 1998*

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# Labor Infrastructure for Agile High Performance Transformations

**Contract Number: F33615-95-C-5512 ALOG Number: 1366**

## Statement of Need

In recent years while high performance and agile workplace innovations have become critical to maintaining jobs and living standards, America's industrial unions have had only a limited ability to invest in developing new internal capacity for promoting those needed changes. In an era of defense and manufacturing downsizing, union membership loss, and subsequent cutbacks in union budgets, manufacturing unions have had difficulty investing in new staff specialists, programs, policies and supportive materials to develop a proactive union agenda for achieving agile high performance (AHP). As a result, the rates of success in implementing AHP production systems in union-represented facilities have been lower than they should have been. To support agile and high performance work systems, union programs and materials are needed for promoting new labor goals including greater investments in continuous skill acquisition; greater empowerment of the production workforce in concurrent design; direct production worker contact with customers and suppliers; shopfloor identification of new technologies, markets, and products; and strategic planning to assure viable employment security for the workforce.

## Approach

The approach used developed a case study methodology involving three teams. Case studies were conducted of networks, model for growing networks and maintaining mature networks, complimentary network material to go with the NIE material, metrics for network effectiveness, replication model development, and creation and refinement of network. Case studies and histories were prepared on two best practice companies and three target companies, establishment of metrics, customization of handbooks, AHP skills training, collection of metrics, and assess, review, revise transformation plan.

## Benefits

An innovation-fostering program of workplace change initiatives in which unions play a proactive role in design and implementation rapidly accelerated the process of upgrading workplace efficiency, flexibility, and agility.

## Status

*Active*
*Start date: February 1995*
*End date: March 1998*

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# Lead Time Reduction

**Cooperative Agreement Number: F33615-96-2-5620 ALOG Number: 1505**

## Statement of Need

Lead time, one of the greatest contributors to product cost, is driven by many factors, including the supplier base, the flow of products through the factory, and administrative processes. These factors have a direct impact on total span time and, therefore, directly contribute to aircraft affordability. Application of lean production principles, which are aimed at reducing waste in all functions of the enterprise, would therefore result in greater efficiency and reduced span times throughout the production realization enterprise, with a commensurate improvement in affordability. This Lean Implementation effort will apply the principles of flow optimization (as identified by the Lean Aircraft Initiative) to reduce administrative function span times, supplier lead time, and factory flow for the F-22 program.

## Approach

The contractor will develop system metrics and a baseline for this effort to use for the subsequent analyses. Three pathfinder initiatives will follow to address each of the three elements of span time (administrative function span times, supplier lead time, and factory flow). The results and key findings of the pathfinders will be incorporated into a series of focused factory demonstrations. During all phases of the effort, close coordination with the F-22 customer is paramount, since implementation throughout the F-22 program is ultimately the means to achieve the envisioned savings.

Administrative Pathfinder: Lockheed Martin will analyze F-22 administrative processes for lead time reduction potential and formulate strategies for application. Reduction strategies may be implemented in a controlled environment to compare metrics with the baseline administrative environment.

Supplier Lead Time Pathfinder: LMAS will evaluate the F-22 supplier base and identify critical path suppliers for the overall weapon system. They will develop quantitative estimates of cost and/or lead time impact of critical path items. Lockheed will then define and execute a JIT demonstration for an F-22 vendor supplied item. Requisite elements of procurement necessary to demonstrate proximity stocking of a component will be included.

Manufacturing Cycle Time Reduction Pathfinder: LMAS will analyze the existing F-22 production flow including: production facility layout, information flow, process flow, product flow, systems architecture, human resources information, supplier relationships, and product development information. Cycle time reduction approaches will be developed.

## Benefits

Estimates for the F-22 indicate that reducing the total production span time from 32 to 24 months could result in significant cost savings.

## Status

*Active*
*Start date: June 1996*
*End date: October 1999*

## Resources

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# Lean Aircraft Initiative

**Cooperative Agreement Number: F33615-93-2-4316 ALOG Number: 1137**

## Statement of Need

Lean concepts present the US military aircraft industry with an opportunity to address the challenges presented by both reductions in DoD procurements and world wide-competition. The adoption of lean principles and practices will allow the industry to meet customer requirements for affordability without sacrificing performance. Through this effort the industry's position as the world's leading producer of advanced technology aircraft systems will be strengthened.

The Lean Aircraft Initiative had its genesis in the five-year International Motor Vehicle Program conducted by a Massachusetts Institute of Technology (MIT) research team as described in the book, "The Machine that Changed the World". The Lean Aircraft Initiative is funded through a cooperative agreement between the government and MIT. Using separate contracting vehicles with MIT, the aerospace industry provides MIT's share of the cooperative agreement with funding from each of the 18 member companies.

The objective of the Lean Aircraft Initiative is to develop a framework for implementation of a fundamentally different, provable better way of manufacturing, enterprise-wide, that would better support the defense aircraft needs over the next 30 years.

## Approach

Phase I of the LAI concluded in September 1996. It established an Executive Board comprised of senior industry, organized labor, and government personnel to assist in steering the effort (i.e., Air Force lead - ASC/CC). Three Lean Forums were conducted in Phase I to transition research findings to the customer base and establish requirements for both technology and acquisition investment planning processes. Based upon MIT LAI research findings, seven advanced manufacturing demonstration projects which pilot the feasibility of lean practices were funded. Industry members are taking LAI findings and applying lean practices within their companies, as evidenced during government/industry information exchanges. LAI Phase II modified the current cooperative agreement by extending the period of performance three years and expanding the scope of government and industry participation.

The primary means of documenting LAI research findings is through the Lean Enterprise Model (LEM). Research results are organized to populate the LEM with data on lean practices, metrics, benchmarking information, interactions, key benefits, major barriers, and mitigation strategies. Phase II continues with many aspects of the existing program (research focus on domestic military aircraft industry, collaborative participation) and incorporates changes based on lessons learned over the past three years (e.g., optimize oversight process). The LAI Phase II works towards a vision of significantly cutting the cost and cycle time for military aircraft while continuing to improve product performance.

## Benefits

The Lean Aircraft Initiative (LAI) is making a difference today. "Lean" is a fundamentally different approach to managing and organizing the enterprise. LAI is accelerating and focusing the pace of change toward lean in the aircraft industry by providing industry leadership with common understanding of principles, priorities and data. LAI provides a collaborative environment to define areas of enabling research and development, benchmark, and share experiences and knowledge.

## Status

*Active*
*Start date: September 1993*
*End date: September 1999*

## Resources

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# Lean Space

**Contract Number: F33615-92-D-5812 ALOG Number: 1523**

## Statement of Need

The Lean Space Initiative (LSI) is an Air Force Space and Missile Systems Center (SMC) and Manufacturing Technology Division initiative to expand the principles and precepts of the Lean Aircraft Initiative (LAI) to the space sector. As with military aircraft, lean production concepts present the US space industry with an opportunity to address the challenges of reduced DoD procurements, foreign competition, and increased emphasis on information dominance through deployment of space assets. The adoption of lean practices can enable the space industry to meet customer requirements without increasing cost or sacrificing performance.

The objective of the Lean Space Initiative is to build upon the achievements of the Lean Aircraft Initiative (LAI), Phase I, and develop a framework for the implementation of a fundamentally new way of doing business to improve affordability of military space assets. The ultimate objective of LSI is to support acquisition to meet defense space needs through the next generation. The initiation of LSI will be preceded by a "Quick-Look" study of critical elements of the Space industry and government customer community accomplished by the Massachusetts Institute of Technology. The quick-look study will determine interest in developing a consortium similar to LAI, develop a Concept of Operations for LSI, and decide on research topics to be undertaken by a consortium of academia, industry and government members. With approval by SMC/CC upon successful conclusion of the study, a consortium will be formed of interested space industry and government agencies.

## Approach

There will be a formal alliance with LAI through the three LAI Integrated Process Teams dealing with Integration, Implementation and Communication, which will provide the primary interface with LAI. There will also be alliances with other related government initiatives, such as the NASA-funded "Process Millennia" effort, the MIT International Motor Vehicle Program, the Fast and Flexible Program and other appropriate initiatives as they form. LSI focus teams tentatively identified for integrative research in cross-cutting topics in the space enterprise include: Risk Assessment and Space Operations; New Technology Impact and Commercialization of Space.

## Benefits

Just as LAI is accelerating and focusing the pace of change toward lean in the aircraft industry, LSI intends to reduce cost and acquisition cycle time, with the additional goal of improving mission responsiveness of US space systems.

## Status

*Complete*
*Start date: December 1996*
*End date: August 1997*

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# Lean Sustainment Initiative

**Contract Number: F33615-96-D-5608 ALOG Number: 1284**

## Statement of Need

This program builds off the Sustainment 2005 Organic Industrial Base assessment which examined areas within the depot maintenance structure requiring fundamental change, either through technology insertion or adoption of supportive business policies and practices. The aging force structure and diminishing budget have elevated the importance of the sustainment mission.

An outgrowth of the Lean Aircraft Initiative, this project will make available to the Lean Logistics (LL) community the unique research experience and capability of the Massachusetts Institute of Technology (MIT) in the area of lean principles, practices, and change strategies. This program is expected to stimulate fundamental change within the entire sustainment enterprise and will emphasize the Air Logistics Centers supplier base.

## Approach

The Lean Sustainment Initiative will distill and disseminate existing MIT lean principles and change management knowledge to Air Force LL personnel. Research of world class lean repair commercial organizations will be conducted and critical lean principle and change management lessons learned will be communicated to LL architects. World class commercial repair processes will be compared to determine what to change and how to best accomplish this.

## Benefits

This program will help identify "best practices" that should be considered for adoption within the Organic Industrial Base, enabling it to eliminate waste and achieve a lean enterprise posture. In addition, it will help establish integrated workload sector enterprises within the organic industrial base from a product/process perspective.

## Status

*Active*
*Start date: April 1997*
*End date: December 1999*

## Resources

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# Metrics for Agile Virtual Enterprises

**Contract Number: F33615-95-C-5513 ALOG Number: 1365**

## Statement of Need

Metrics are essential for any new management philosophy. Today, there are some benchmarking techniques, developed largely by the Agility Forum. These are better than nothing, but they are subjective. With some effort, they can be used to compare before and after states. But they cannot be used in an active way by managers in day-to-day decision tools to help decide upon and implement the optimum agility tactics. The objective of this project was to discover, understand and usefully describe formal, quantitative-based metrics associated with agility in the virtual enterprise. These metrics are of the type that managers can use in making decisions.

## Approach

The approach heavily leveraged prior unpublished work in this area. It also leveraged, coordinated, and supplemented work planned in other forums. Overall, the effort was divided into three parts. The first part of the effort focused on the definition of the individual metrics and their formal linkage to conventional management science that supports strategies in enterprises. The focus was primarily on commercial manufacturing enterprises, especially the formation of agile virtual enterprises. The second part of the effort focused on the formal linkage of the metrics to conventional information technology that currently supports all phases of manufacturing enterprises. The focus here was on determining standard methods for tool builders to incorporate the metrics in their products. The third part of the effort focused on validating the metrics, and their linkages, on a real, progressive virtual enterprise in the automotive domain.

## Benefits

The approach developed assured the acceptance and utility of the metrics. That is, the metrics were formally established within the context of prevailing management science. Though intuitive, they also have a formal, auditable chain of cause and effect which can trace the metrics to high level strategic metrics of the enterprise. They also have a mathematical basis which is linked to process boundaries and implementation opportunities in the information infrastructure. This assures that the metrics can be implemented in tools which can easily integrate into the enterprise's tools and processes.

## Status

*Complete*
*Start date: January 1995*
*End date: May 1997*

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# Military Products from Commercial Lines

**Contract Number: F33615-93-C-4335 ALOG Number: 1254**

## Statement of Need

The shrinking defense industrial base and weapon systems affordability are critical issues facing all DoD programs. This pilot attacks the issues of dual-use and affordability by producing military components on a commercial line at lower cost and comparable quality to those produced on a dedicated military line. Digital electronic modules compatible with the F-22 Advanced Tactical Fighter and the RAH-66 Comanche Helicopter will be processed on a commercial automotive manufacturing line. The data collected throughout the program will be used by the F-22 SPO and the RAH-66 PMO to determine if cost savings are sufficient to warrant future purchases of commercially manufactured military electronic modules. The objective of this project is to apply Lean principles to demonstrate the commercial manufacture of military electronics modules, and measure and transfer results.

## Approach

Using an integrated product team (IPT) approach, the pilot is addressing business practice (BP), manufacturing infrastructure (MI), and process technology (PT) issues. The BP IPT will recommend contractual and technical business practice changes to facilitate the integration of commercial suppliers into the industrial base. The MI IPT works communication issues between design and manufacturing engineers and will enhance computer integrated manufacturing (CIM) capabilities for the pilot demonstration. Both BP and MI recommendations will be implemented during the PT demonstration in which modules compatible with the F-22 and the Comanche will be commercially produced. The PT IPT is responsible for the redesign and manufacturing of the modules.

## Benefits

Incorporation of commercially produced military avionics on military aircraft will dramatically reduce the cost of electronic suites (between 30-50 percent) by taking advantage of economies of scale and automated manufacturing process through coproduction on commercial lines. Additional programs identified as potential beneficiaries include the F-14, F-18E/F, Pave Pace, F-15, F-16, F-117, B-1, B-2, UAV, and JSF. Expanded access to commercial suppliers through a broadened definition of commercial products, simplified acquisition procedures, and reduced specification/oversight will shorten response times and increase competition.

## Status

*Active*
*Start date: May 1994*
*End date: October 1998*

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# Military Products Using Best Commercial/ Military Practices

**Contract Number: F33615-93-C-4334 ALOG Number: 1255**

## Statement of Need

Incorporating the best commercial practices into defense production facilities and expanding the potential for dual-use factories ultimately means more affordable weapon systems. The objectives of this pilot are to successfully demonstrate the ability to build a more affordable, lighter weight C-17 horizontal stabilizer in an integrated factory using best commercial/military practices, and to achieve equal or better quality levels, reduced weight, and a decrease in cost when compared to the existing business and performance baseline. This program has been strongly endorsed by the C-17 System Program Office (SPO). Data collected throughout the program will be used by the C-17 SPO to determine if cost benefits are sufficient to warrant incorporation of revised business practices and the improved stabilizer into their program. Transition of business policies and practices, manufacturing infrastructure, and process technology improvements to the C-17 SPO and the aerospace community will be a key measure of the pilot success.

## Approach

The pilot contract is structured in two consecutive phases. The Development Phase, will focus on selecting and prototyping the best business policies and practices, manufacturing infrastructure, and process technology improvements to be demonstrated in Phase II. The Demonstration/Validation Phase, of the pilot effort will finalize the design, fabricate a full-scale improved C-17 stabilizer using the business policies and practices and manufacturing infrastructure improvements from Phase I, while measuring improvements from the business policies and practices, manufacturing infrastructure, and process technology changes. A structural certification test of the stabilizer will be conducted at the conclusion of Phase II.

## Benefits

Benefits include: demonstrated 50 percent cost savings and 20 percent weight savings resulting from reduced contractor overhead (personnel and reporting), and the use of best commercial/military practices in quality, financial and contracting approaches, when compared to the pilot baseline. The pilot will also provide sufficient data to support permanent changes to business policies and practices (FAR, DFAR, Mil SPECs, etc.) that eliminate entry barriers and enhance Department of Defense's ability to contract with firms employing "best practices" within the industrial base. In addition, the more affordable, lighter weight C-17 horizontal stabilizer torque box will be incorporated onto the C-17 Globemaster in late 1998.

## Status

*Active*
*Start date: June 1994*
*End date: May 1998*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*McDonnell Douglas Corp.*

*JDMTP Subpanel:*
*Advanced Industrial Practices*

# Modular Factory for Electronic Warfare Component Manufacturing

**Cooperative Agreement Number: F33615-95-2-5564 ALOG Number: 1264**

## Statement of Need

The Lean Aircraft Initiative has identified flow optimization as an enabling practice for the production enterprise. Benchmarking data from the LAI suggests that a modular organization of the factory is a powerful means of optimizing flow. Derivation and demonstration of the modular factory concept for the defense production environment requires consideration of business practice changes, infrastructure improvements, and identification of the barriers and disincentives to its implementation. This lean implementation effort focuses on demonstration of the modular factory concept against electronic warfare component manufacture, demonstrating emphasis on up-front assessment of cost drivers and affordability concerns.

The Microwave Power Module (MPM) is an enabling technology for the 21st century. MPMs are complete microwave amplifiers of unprecedented miniaturization. Unsurpassed performance in terms of broadband power and efficiency has been demonstrated, but the major challenge prohibiting large scale insertion at this time is cost. Furthermore, defense acquisition focus has changed from performance at any cost to affordability, placing additional pressure on the industrial base. For a defense producer to meet the challenge of reduced cost while attracting a commercial business base, a flexible or modular approach to production is warranted.

## Approach

The modular factory is a reorganization of production resources into semiautonomous modules, each with total responsibility and authority for a set of processes, adding value to the product to ensure success for the entire enterprise. Typically, modules are arranged within the factory around the assembly sequence, with the next higher assembly operation as the customer. The module is characterized by: empowerment of workers and teams, emphasis on training for skill interchangeability, dedicated capital equipment, aggressive inventory reduction, focus on work flow velocity, shop floor density to reduce transportation time, and gain-sharing incentives for employees.

Northrop Grumman Electronic and Systems Integration Division will develop, through an 18-month pathfinder effort, a streamlined design-to-manufacturing link that includes an automated equipment interface with in-house design tools, a design database, and a networked data link between engineering and manufacturing. These capabilities will be implemented for a pilot demonstration of a modular factory for the production of Microwave Power Modules (MPMs).

## Benefits

This project will apply the leading edge production philosophy of modular flow (as identified by the Lean Aircraft Initiative) to the production of MPMs. Expected benefits include 40 percent reduced cost, 40 percent shorter design-to-market cycle time, and higher hardware reliability. Furthermore, an affordable source of MPMs will emerge to support various new and existing systems, upgrades and modifications, and spares requirements. There is long-term potential to open commercial markets for this product class.

## Status

*Active*
*Start date: October 1995*
*End date: October 1998*

## Resources

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*Air Force Funded*

*Contractor:*
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*JDMTP Subpanel:*
*Advanced Industrial Practices*

# National Center for Manufacturing Science

**Contract Number: F33615-96-C-5619 ALOG Number: 73**



## Statement of Need

Once the U.S. was the world leader in the manufacture of machine tools; now the U.S. ranks fourth behind Japan, Germany, and Russia. In just six years, the U.S. imports of iron and steel mill products have surged to eight times the exports of those same countries. Many reasons existed for the nation's increase in imports over exports, and factors originating in manufacturing were only partially responsible. The first step to rectifying the problem was to conduct the research and technology transfer in manufacturing engineering required to return U.S. companies to world-class manufacturing leaders.

The National Center for Manufacturing Science (NCMS) is a nonprofit research consortium of U.S. manufacturers, organized under the 1984 National Cooperative Research Act. It was designed to fund manufacturing research projects that would meet the needs of U.S. industry, including the U.S. machine tool industry, and promote the use of new technology in U.S. manufacturing companies. A major objective of the NCMS was to provide a focus for the cooperative efforts within industry, and to establish a research agenda to address the manufacturing needs of U.S. industries in a global economy. This agenda was based on the stated needs of the member companies and was organized as a series of topical areas that encompassed individual manufacturing research and development projects. These projects were to be executed through a combination of private, state, and federal funds. In their individual R&D efforts, companies were often forced to choose between the short-term, incremental improvements they needed to stay in business, and the long-term, "breakthrough" technologies they needed to bolster their global competitiveness in the future. By offering effective leveraging of their resources, NCMS helped companies achieve both objectives. Companies were only as strong as the supplier base on which they depended. NCMS provided the "safe harbor" environment that fostered and encouraged the mutual participation of users, suppliers, and others in a collaborative process - a process that involved collective decision-making, execution, and management of technology development programs.

## Approach

NCMS currently has a membership of two hundred companies which includes the Who's Who of American industry. The NCMS technical agenda is member driven and 90 percent of the technical projects are planned and performed by the membership companies. The technical projects are characterized as being pervasive collaborative efforts wherein NCMS provides 35 percent of the funding and remaining 65 percent funding is provided with in-kind funds from the participating companies. There are seven Strategic Initiative Groups (SIGS) which plan and approve the NCMS technical agenda and technical projects which are performed by the Technical Advisory Groups (TAGS) made up of member companies. These seven SIGS embody the following technical areas: Electronics, Materials and Processing, Production Equipment, Management Practices, Computer Integrated Operations, Environmental Conscious Manufacturing, and Services. Within these seven SIGS, NCMS is performing approximately forty collaborative technical projects.

## Benefits

The benefits of this program include the promotion of research and technology transfer in manufacturing engineering in the United States. Development of a defense-driven, industry-led collaborative technology development agenda will have both broad application across Department of Defense weapon systems, contractors, and commercial industry and their supplier tiers, and have the capability of enhancing national security and the overall competitiveness of U.S. manufacturers.

## Status

*Active*
*Start date: April 1996*
*End date: April 1999*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*National Center for Manufacturing Science*

*JDMTP Subpanel:*
*Advanced Industrial Practices*

# National Excellence in Materials Joining Education & Training

**Grant Number: F33615-94-1-4416    ALOG Number: 1224**

## Statement of Need

Maintaining a competitive edge in the global marketplace requires U.S. manufacturers to continuously improve product quality, reduce costs and respond quickly to changing markets and customer demands. Materials joining is a critical "enabling" technology that permeates the manufacturing arena, including both military systems and commercial products. In Ohio, over 500,000 workers are employed in industries dependent on materials joining and allied technologies. A major deficiency in both the Ohio and U.S. manufacturing infrastructure is the absence of an engineering workforce educated and trained in the various aspects of materials joining. As the technology becomes more sophisticated and the requirement for a highly educated and trained materials joining workforce increases to meet ISO 9000, CEN and NAFTA requirements, this deficiency will increasingly place U.S. industry at a competitive disadvantage.

The objective of this effort is to establish a regionally based program entitled National Excellence in Materials Joining Education and Training (NEMJET) which will serve as a model to retrain the manufacturing workforce using a systematically designed and coordinated instruction base. It will provide a nationally approved means for attaining industry-recognized diplomas, certificates, and degrees.

## Approach

The program uses a modular architecture for the development of instructional materials that provide tremendous flexibility in the delivery of NEMJET. The program is primarily designed to provide training at the engineer and technologist levels and is structured to accommodate individuals with diverse technical backgrounds. Courses are offered on a yearly basis in two week blocks in both October and June. NEMJET modules are also incorporated into the welding engineering curriculum at Ohio State University.

## Benefits

This unique and innovative program will build upon existing programs and use a strong regional network of academia and industry to retrain and reorient the manufacturing workforce to meet a diversity of pertinent industry needs. Once developed, NEMJET will serve as a national model for the establishment of other programs critical to the manufacturing infrastructure.

## Status

*Active*
*Start date: March 1994*
*End date: September 1998*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Ohio State University*

*JDMTP Subpanel:*
*Advanced Industrial Practices*

# OPNET Industrial Base Simulation

**Contract Number: F33615-93-D-5101 ALOG Number: 1515**

## Statement of Need

The requirement is to simulate replenishment of the munitions industrial base and reveal problems and opportunities for investment. The program originated from readiness concerns over the health of the munitions industrial base.

## Approach

OPNET links the war planning demands for munitions with the industrial supply of munitions during replenishment, giving planners a unique view of the impact of industrial capabilities on future scenarios. OPNET ties multiple demands to a manufacturing flow and supplier relation infrastructure to provide insight into the ability to support multiple requirements. Nearing completion of output enhancements (graphical capabilities) to show the modeling capabilities of results of interactive suppliers in the munitions industrial base, the focus is on replenishment, determining the time required to recover and restore readiness to a pre-specified level, and pinpointing critical issues within the industrial base subtiers for weapons of interest. The supply and logistics module calculates transportation times and determines the type and quantity of munitions (or whatever resources) required. The drawdown module allocates these resources (the results of the supply and logistics module) by scientific method against targets in an optimal manner, and can be used to quantify cost, conflict duration and attrition. Outputs of the first two modules can be substituted through other sources. With a OPNET Users' Group online, the tool is currently available and operational to the extent of enhancements completed, but not supportable for new applications without specific application funding. Industry is invited to seek agreements with the USAF and DSI for their applications, and discussions are ongoing. The model is flexible to accommodate low, medium and high intensity conflicts, deriving the target set from official sources.

## Benefits

OPNET has applications to wargames, development planning, acquisition strategy, manufacturing flow, and subcontractor management. OPNET enhances contingency planning through simulation for a win-win situation for customers and suppliers. Decisions can be made in advance in order to minimize the effects of the erosion of the most critical resources. Successful completion of this project enables the customer to quickly and accurately analyze the potential shortfalls in the current inventory. The relative health and ability of the industrial base to meet the future needs of the defense community can be assessed/measured.

## Status

*Active*
*Start date: January 1994*
*End date: March 1998*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*Decision Sciences Inc.*

*JDMTP Subpanel:*
*Advanced Industrial Practices*

# Practice-Oriented Masters Engineering Program

**Grant Number: F33615-94-1-4422 ALOG Number: 1225**

## Statement of Need

The National Research Council's study of research priorities for U.S. manufacturing identified manufacturing skills improvement as one of the critical needs. This report stated, "What modern manufacturing needs -- and is not getting -- are master technicians and Renaissance engineers." The same theme in different words is heard from senior executives who complain that functional barriers within their organizations present roadblocks to developing required competitive capabilities. Organizing the business teams frequently exposes a new problem -- the specialists do not have sufficient understanding of the other functions to perform effectively as a member of the business team. The current university system produces engineers with depth in fundamentals but insufficient skills for professional practice, particularly in manufacturing. Students typically receive little, if any, exposure to manufacturing.

The objective of this effort is to establish a practice-oriented master's engineering program (POMEP). The student simultaneously receives a M.S. from an engineering department plus a certificate in manufacturing engineering. The key components are a major in a manufacturing subject area, an interdisciplinary principals of manufacturing core involving both engineering and business, plus a practicum in industry.

## Approach

POMEP is a practice-oriented manufacturing engineering program which will be developed in parallel at the Ohio State University and Drexel University. The director at Ohio State University is R. Allen Miller, Professor of Industrial and Systems Engineering. The director at Drexel is Shlomo Carmi, chair of the Department of Mechanical Engineering and Mechanics. Overall responsibility for the technical program is held by R. Allen Miller as the project principal investigator.

POMEP start-up tasks will be performed by academic coordinating committees and industrial advisory committees at each institution. Coordination between the two institutions during the start-up phase was achieved primarily through frequent communication between the two directors.

## Benefits

The Partnership for Systemic Change in Manufacturing Education brought together two major forces for change in engineering education --- the Engineering Research Center for Net Shape Manufacturing (ERC/NSM) and the Gateway Engineering Education Coalition. The ERC program was instituted to "change the culture of engineering education and research." The engineering coalitions were charged with improving undergraduate education. Coupling this ERC, one of the very few manufacturing ERCs, with an education coalition produced a team uniquely qualified to bring about needed systemic change in manufacturing education. By expanding and integrating the programs of the ERC/NSM and Gateway, a new model was created and has important immediate impacts on manufacturing education for the emerging global and dual-use market places.

## Status

*Complete*
*Start date: March 1994*
*End date: November 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Ohio State University*

*JDMTP Subpanel:*
*Advanced Industrial Practices*

# Qualification Criteria for Agile Enterprises

**Cooperative Agreement Number: F33615-95-2-5522    ALOG Number: 1364**

## Statement of Need

Agile manufacturing requires rapid customer/supplier partnering to achieve short product development life cycle. Fundamental to the shortening of these development activities is rapid and near-instantaneous qualification of supply partners. Recent experience of world class manufacturing corporations reflects two important facts regarding suppliers. First, greater than 75 percent of new product materials and components are provided by the supplier community. Second, over 80 percent of new product development costs are defined within the early conceptual phase of product development. To achieve customer satisfaction, including affordability and response time to customer demand, agile materials and supply chain management is of strategic importance. The objective of this program was to identify and assess the key elements of customer/supplier relations necessary to optimize the supply chain competitiveness.

## Approach

The approach to the program objectives were performed through round-table meetings and site visits with industry members. This determined best practices and areas requiring improvement, developed framework for supply chain management and associated metrics, and demonstrated modeling and industrial setting.

## Benefits

Payoffs include pre-qualification of potential customer/supplier partners to avoid delays in conceptual development, reduced product life-cycle costs, and assured a high level of quality in supplier products.

## Status

*Complete*
*Start date: March 1995*
*End date: January 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Consortium for Advanced Manufacturing*

*JDMTP Subpanel:*
*Advanced Industrial Practices*

Electronics

# Acoustic Wave Inspection of Silicon-on-Insulator (SOI) Wafers

**Contract Number: F33615-97-C-5135 ALOG Number: 1534**

## Statement of Need

State-of-the-art wafer processing is only as good as the quality of the starting substrate materials. As technology has greatly reduced the size of active components and allowed the integration of vast amounts of circuitry on a chip, the starting material quality has become a major variable in determining the final yield of a product. Not only is it important to have high wafer surface quality, it is equally important to have substrate crystal uniformity: i.e., defect-free beyond the depth of the junctions of the active devices.

The objective of this project was to determine the silicon dislocation density in a silicon overlayer using acoustic wave analysis on the thin film.

## Approach

The approach was performed in four tasks:
Task 1 - Material fabrication.
Task 2 - Dislocation etching and optical characterization.
Task 3 - ISIT measurements on this film silicon.
Task 4 - Correlation of etching analysis and ISTS measurements.

## Benefits

The product is valuable to the semiconductor industry in improving fabrication yields and reducing overall costs.

## Status

*Complete*
*Start date: April 1997*
*End date: October 1997*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*IBIS Technology Corp*

*JDMTP Subpanel:*
*Electronics*

# Active Matrix Liquid Crystal Display for Manufacturing Technology

**Cooperative Agreement Number: MDA972-93-2-0016 ALOG Number: 1172**

## Statement of Need

The Department of Defense has identified world-class active matrix liquid crystal display (AMLCD) manufacturing capability as "defense critical" based on the needs of the F-22 and other high-priority aircraft cockpit applications. In order to demonstrate the establishment of this critical manufacturing capability, a pilot manufacturing demonstration facility is expected to be established and demonstrated on current technology products. The pilot demonstration facility should also serve as a focal point for exploitation of the next generation AMLCD. A portion of the facility should be dedicated to next generation research. The facility's processes, equipment and product flow will be adaptable to pilot runs of the next generation products. The primary purpose of this program is the design, construction and operation of a world-class Pilot Demonstration Facility (PDF) for high yield productions of AMLCDs. Upon transition to production, the PDF will be capable of providing a sufficient number of high quality displays to meet a substantial portion of the government's needs through at least the end of the decade.

## Approach

Specific demonstration products are to be defined during Phase I of the effort, and one specific criterion for selection is utility to a specific user. Other Phase I performance requirements are the definition and baselining of critical processes, purchase, installation and characterization of critical process equipment, and design of process controls including in-situ process monitoring and measuring equipment. Phase II shall focus on manufacturing process improvement and product demonstration. Process improvement shall be based upon a disciplined approach utilizing such methods as Taguchi, Pareto, Quality Function Deployment, and Designed Experiments. Product demonstrations shall include those specific products of user interest defined in Phase I. A primary deliverable of Phase II shall be a detailed plan for transitioning the pilot manufacturing capability to production of both military and commercial products as warranted during the three year period following the completion of Phase II. The PDF will serve as a beta site for the High Definition Display Consortium.

## Benefits

This research will result in the availability of competitively-priced flat panel AMLCDs from a U.S. manufacturer, and the establishment of a center for the development of manufacturing techniques necessary for the next generation (e.g. polysilicon and other) display technology.

## Status

*Active*
*Start date: August 1993*
*End date: August 1998*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Optical Imaging Systems Inc.,*

*JDMTP Subpanel:*
*Electronics*

# Affordable Integrated Optic Chips

**Contract Number: F33615-96-C-5625 ALOG Number: 1458**

## Statement of Need

Lithium niobate modulators have been available commercially for about ten years. Standard products from different vendors consist of intensity modulators, phase modulators, directional couplers, integrated optic circuits (IOCs) for fiber optic gyroscopes (FOGs), etc. Bandwidths extend from DC to 20 GHz and wavelengths cover the range from 0.6 μm. Although the available products are diverse, the price of all products is in the range of several thousands of dollars per unit. Such high prices are a significant barrier to the large scale deployment of lithium niobate integrated optic devices in most applications, specifically for FOGs.

The objective of this Phase I SBIR was to develop manufacturing technologies for fiber pigtailed lithium niobate IOCs for FOGs which will reduce unit cost to $100. The opportunity here was to develop a manufacturing technology that would enable the economic, large scale use of IOCs for FOGs and for other commercial applications such as CATV, optical sensors medical and various other industrial applications, and high rate data communication for deployment of the Information Highway.

## Approach

The contractor documented the macro-flow and micro-flow for existing fabrication processes. The preliminary cost model was analyzed, and a two-level quality function deployment (QFD) matrix was developed. The program plan included a variability reduction roadmap showing how tools (such as design of experiments, quality function deployment, and statistical process control) were used to obtain programmatic goals. This program culminated in a feasibility demonstration to provide confidence in the approach.

## Benefits

Several market analysts estimate the fiber optic sensor market by the year 2000 to approach $2 billion. The three largest segments of the market will be biomedical sensors, aerospace sensors and military applications. Several aerospace applications will involve inertial navigation systems and require deployment of fiber optic gyroscopes which are relevant to this program.

## Status

*Complete*
*Start date: April 1996*
*End date: October 1996*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*Ramar Corporation*

*JDMTP Subpanel:*
*Electronics*

# Airborne Warning and Control System (AWACS) Salvageable Electron Gun



**Contract Number: F33615-96-C-5103 ALOG Number: 1464**

## Statement of Need

At the present time, when the vacuum integrity of an airborne warning and control system's (AWACS) klystron power amplifier (KPA) is damaged or destroyed, the KPA can be repaired, rebuilt and made serviceable once more. If the need is there, the KPA can be rebuilt several times. Unfortunately, each time the vacuum integrity of the KPA is lost, the electron gun must be removed and scrapped. If the KPA is to be rebuilt, it must have a new electron gun.

The electron gun used in the AWACS KPA uses an oxide coated cathode. This means that the electron emission surface of the cathode is applied to a substrate. The cathode coating material is converted from a mixture of carbonates to a mixture of oxides. The conversion occurs at high temperature during the exhaust/bakeout processing of the KPA. The conversion is necessary to provide a material that readily emits electrons. Once the conversion has taken place, the oxide emission material will be destroyed if it is subjected to any amount of air. It cannot be reprocessed and made useful again. This electron gun also must use grids to control the electron beam emitted from it. The cathode is coated, and then the grids are installed. The mechanical design of the electron gun is such that these grids cannot be removed without inflicting non-repairable damage to the electron structure. Thus, every time the KPA loses its vacuum, the electron gun must be scrapped. The method of attachment of the electron gun to the high voltage insulator provides a structure that does not permit the electron gun to be separated from the insulator assembly without excessive damage to both. This results in the scrapping of the insulator assembly each time the electron gun is removed from the KPA. The objective of this program is to address manufacturing process improvements for the successful removal of the AWACS electron gun from the klystron power amplifier. This will allow the electron gun to be repaired and reused instead of scrapped.

## Approach

A manufacturing process improvement will demonstrate the successful removal of the electron gun from the high voltage insulator assembly, and the removal of the grids, thus allowing for repair. The current manufacturing process will be baselined through design of experiments and statistical process control methodologies to improve the process and monitor validation of the process improvement.

## Benefits

This project will reduce the cost of the KPA by the number of electron guns that are reused instead of scrapped and replaced. This would result in a lower cost to the customer. Eventually, as the existing guns are replaced in the Air Force KPA inventory through repair programs, the cost of KPA repair will go down as a result of the ability to reuse a significant percentage of the electron guns.

## Status

*Complete*
*Start date: July 1996*
*End date: November 1997*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*Litton Corporation*

*JDMTP Subpanel:*
*Electronics*

# Alternatives to the Use of Fluoride and Hydrogen Fluoride in Electronics

**Contract Number: F33615-95-C-5501 ALOG Number: 1328**

## Statement of Need

Silicon wafers have become the platform for many non-integrated circuit (IC) devices. These non-IC technologies have developed into sizable markets, and are growing very rapidly. Most of these devices require three-dimensional (3-D) or non-IC type structures in their operation or fabrication. The formation of 3-D features is very restrictive in terms of the final device size and shape because it relies on crystal plane etching. The toxicity of the chemical etchants, particularly hydrogen fluoride, and interferences between the chemicals are especially prohibitive.

The objective of this project was to greatly reduce or eliminate the use of free fluoride and hydrofluoric acid in the fabrication of structures formed in silicon for electronic (but non-integrated circuit) uses. The target applications included: microelectronic-machined structures (MEMS), high density multi-chip modules (MCM-D), sensors (particularly pressure sensors), silicon solar cells, hermetic packages for electronic devices, and micro-optical components as used in optoelectronic devices and silicon optical bench products.

## Approach

There were three areas of work in this project. The first developed the chemical basis for the etching process. The second explored a variety of applications defining the operational parameters and in the process targeting the technology toward the most appropriate applications. The third area brought on-board appropriate member companies as team members. While the three tasks were undertaken simultaneously, there was an evolutionary progression to their order. Capabilities, resolution, and operational parameters were defined before companies could commit to specific implementations.

## Benefits

The benefits of this project include:

- The process significantly reduces the use of fluorides in the etching of silicon.
- It provides a high-resolution, spatially selective etching method where smaller, more valuable devices can be fabricated.
- The 3-D features can be fabricated at virtually any point in the process sequence so as to make the formation of complex devices easier. In some cases, it provides the only route to fabrication.
- The rate of etching silicon is very high and can be performed without the need for external masks. This provides a rapid, low cost manufacturing technology.
- The etching process can be designed to etch Si without dissolving $SiO_2$. Thus, $SiO_2$ can be used as the etch mask reducing the consumption of polymeric and other masking materials. This is feasible because the complexing species for Si and $SiO_2$ can be controlled independently here.
- The etch rate can be directly monitored for accurate process control.

## Status

*Complete*
*Start date: January 1995*
*End date: September 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Georgia Institute of Technology*

*JDMTP Subpanel:*
*Electronics*

# Development of Affordable Optic Chips

**Contract Number: F33615-97-C-5124 ALOG Number: 1538**

## Statement of Need

The overall goal of this effort is to reduce the cost of pigtailed integrated optic chips (IOCs), which are a key component used in fiber optic gyros (FOGs), to less than $100 in large volume production (6000 inertial measurement units (IMUs) per year).

The objective of this Phase II SBIR is to develop manufacturing technologies for fiber pigtailed lithium riobate integrated optics chips (IOCs) for interferometric fiber optic gyros (IFOG) that will reduce the unit cost to $100.

## Approach

The approach is as follows:

- Achieve single step cut and polish.
- Develop dry polish for silicon V-groove carriers.
- Develop cost effective methods of cleaning and handling of lithium riobate wafers and silicon fiber carriers.
- Enhance the basic structure of the fiber carriers and the active alignment station to achieve 50DB polarication extinction.

## Benefits

Fiber optic gyros have numerous applications in both the commercial and military markets, primarily in the area of navigation (automobiles, airplanes, and ships). Cost will be reduced to less than $100 per unit.

## Status

*Active*
*Start date: March 1997*
*End date: March 1999*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*Ramar Corp*

*JDMTP Subpanel:*
*Electronics*

# Development of a Flat Panel Display Laser Interconnect and Repair System

**Contract Number: F33615-93-C-4327 ALOG Number: 1203**

## Statement of Need

Current production equipment is based on modification of production IC wafer equipment. Size is limited to 300 mm square and capable of processing only one, 8" x 10" display per run. Amorphous silicon displays require off-display driver circuits and over 2400 interconnects for one (1) 640 mm x 480 mm color pixel (8" x 10") display. In addition, final assembly test and inspection reduces display yield by 40-50 percent and essentially doubles display cost. Moreover, no test or repair capability exists for panels during assembly. By conversion to a polysilicon active matrix liquid crystal display (AMLCD), interconnects will be reduced to 30 (approximately one hundredfold reduction) and assembly costs will be reduced.

ESI was tasked to develop a laser Tape Automated Bonding (TAB)-to-Flat Panel Display (FPD) bonding system to demonstrate drive chip attachment to and repair of large area FPDs with the improved nominal materials costs (20¢/panel) and with higher throughput and yield. The TAB-to-FPD bond has the desirable physical properties of a metal-to-metal bond such as high strength, low electrical resistance (<50μOhm/lead), high current (~1 A/lead) capability. The laser bond method bypasses thermal processing of the complete panel width that leads to Thermal Coefficient of Expansion (TCE)-induced alignment difficulty required by Anisotropic Conductive Adhesive Film (ACAF) technology. It is an extremely flexible attachment technique that is low in material cost and applicable to future technological developments such as flip-chip bonding.

## Approach

Initial work focused on the TAB-to-Gold (Au) bump process using easily obtainable integrated circuits (IC) samples. Derived optimal laser processing parameters including power, pulse duration and shape, and optics. Several different metallizations and gas ambients were tried in conjunction with varying laser process parameters. Once the process is optimized, TAB-to-FPD bonds could be tested for electrical resistance, bond strength, and joint thermal stability.

## Benefits

The TAB-to-FPD bond has the desirable physical properties of a metal-to-metal bond such as high strength, low electrical resistance (<50μOhm/lead), high current (~1 A/lead) capability. The laser bond method bypasses thermal processing of the complete panel width that leads to Thermal Coefficient of Expansion (TCE)-induced alignment difficulty required by Anisotropic Conductive Adhesive Film (ACAF) technology. It is an extremely flexible attachment technique that is low in material cost and applicable to future technological developments such as flip-chip bonding.

The draft final report will be available in January 1998.

## Status

*Complete*
*Start date: September 1993*
*End date: May 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Electro Scientific*

*JDMTP Subpanel:*
*Electronics*

# Development of a Low Cost Environmentally Benign All-Sputtered Fabrication of Thin-Film Transistors for Active Matrix Liquid Crystal Displays



**Contract Number: F33615-94-C-4446 ALOG Number: 1281**

## Statement of Need

The most critical problem in cockpits today is the lack of pilot/crew situation awareness. Present cockpit displays, namely cathode ray tubes (CRTs), have several disadvantages which limit the fusing of the data and presenting situation information to the pilot. Active matrix liquid crystal displays (AMLCDs) are the cockpit designer's choice for replacing CRTs since they are sunlight readable with full color capability. In addition, AMLCDs provide a large viewing area with small instrument depth and do not fail catastrophically rendering the display inoperable.

The active matrix liquid crystal technology must be developed in the United States so that the displays required by the military are available from domestic sources. These programs, under DARPA/MANTECH auspices, will develop the manufacturing equipment necessary to establish the domestic manufacturing capability for large area active matrix liquid crystal displays. The Tri-Service needs for AMLCD cockpit displays are approximately 45,000 by the turn of the century. Most military display requirements are common with commercial aircraft and, in many instances, the critical component (AMLCD active glass) is common with commercial applications, including portable computers, virtual reality workstations, and television receivers.

The goal of this effort is to demonstrate all-sputtered thin film transistors (TFTs) equal in quality to TFTs produced by plasma-enhanced chemical vapor deposition (PECVD). Like PECVD, an all-sputtered process could be accomplished commercially as a unified process with sequential deposition in a single cluster tool.

## Approach

The program is divided into three principle phases, each with its own set of tasks:

Phase I: A short-term low-budget phase intended to demonstrate TFT quality silicon nitride for gate dielectric (and less critically, for passivation).

Phase II: Process development of all required films on 150 x 150 mm 7059 glass substrates. The development work is carried out in Intevac's existing DDS-100 R&D multi-station chamber. The goal of this phase is to demonstrate working TFTs fabricated by an all-sputtered process.

Phase III: Process scale-up of all required films on commercial size (450 x 550 mm, 500 x 500 mm) 7059 glass substrates. The development work is conducted in Intevac's existing commercial D-Star cluster tool, with the goal of demonstrating working TFTs fabricated by an all-sputtered process.

## Benefits

The integration of the TFT deposition into an all-sputtered manufacturing technology has substantial benefits for the display industry, including: proven high-rate manufacturing process; easily scaled for good uniformity over large areas; reduced particle generation; faster thermal cycles for higher throughput; elimination of toxic gases; reduced material consumption; and amenable to environmental cleanliness. This technology addresses concerns of the AMLCD industry for better yields, higher throughput per dollar of equipment, and decreased maintenance. It also provides energy-efficient, materials-efficient, and nonhazardous nonpolluting manufacturing technology necessary for the U.S. to achieve world class competitive status.

## Status

*Active*
*Start date: September 1994*
*End date: December 1997*

## Resources

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# Development of an Adaptive Laser Imaging Tool for Large Area Flat Panel Display Mask Generation and Maskless Patterning

**Contract Number: F33615-94-C-4441 ALOG Number: 1282**

## Statement of Need

The most critical problem in cockpits today is the lack of pilot/crew situation awareness. The present cockpit displays, namely cathode ray tubes (CRTs), have several disadvantages which limit the fusing of the data and presenting situation information to the pilot. Active matrix liquid crystal displays (AMLCDs) are the cockpit designer's choice for replacing CRTs since they are sunlight readable with full color capability. In addition, AMLCDs provide a large viewing area with small instrument depth and do not fail catastrophically rendering the display inoperable.

The active matrix liquid crystal technology must be developed in the United States so that the displays required by the military are available from domestic sources. These programs, under DARPA/MANTECH auspices, will develop the manufacturing equipment necessary to establish the domestic manufacturing capability for large area active matrix liquid crystal displays. The Tri-Service needs for AMLCD cockpit displays are approximately 45,000 by the turn of the century. Most military display requirements are common with commercial aircraft and, in many instances, the critical component (AMLCD active glass) is common with commercial applications, including portable computers, virtual reality workstations, and television receivers.

The primary objective of this program is a laser imaging system, the Adaptive Laser Imaging Tool (ALIT), capable of patterning 5 mm features over a 24" x 24" glass flat panel display or photomask substrate. The development of the Adaptive Laser Imaging Tool will reduce the need for complex array of capital equipment needed to support large area steppers. An integral automatic optical inspection module will permit in-situ layer-to-layer overlay measurement and correction for flat panel displays.

## Approach

This program consists of three phases to develop an Adaptive Laser Imaging Tool (ALIT), consisting of an ultraviolet laser imager coupled with a limited automatic optical inspection (AOI) system, either for direct writing or mask generation of flat panel patterns such as phosphors, electrodes, passive devices, active devices, and color filter polymers. Substrate inspection can be conducted prior, during, and after the feature patterning process, allowing adaptive patterning for accurate overlay to prior image layers.

## Benefits

The adoption of the ALIT will reduce the need for the complex array of capital equipment needed to support large area steppers. An integral automatic optical inspection module will permit in-situ layer-to-layer overlay measurement and correction for flat panel displays.

## Status

*Active*
*Start date: July 1994*
*End date: March 1998*

## Resources

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*JDMTP Subpanel:*
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# Development of Benzocyclobutene/ Perflourocyclobutane-Based Color Filter Coatings for Display Applications



**Contract Number: F33615-94-C-4407    ALOG Number: 1213**

## Statement of Need

Active Matrix Liquid Crystal Displays (AMLCD) are the choice for replacing present cockpit displays because they can be viewed in sunlight with full color capability. AMLCDs provide a large viewing area and have small instrument depth. AMLCDs take up less space and require less power. They have the potential of transferring to commercial aircraft, portable computers, virtual reality workstations and televisions. Currently, there is a limited domestic capability to manufacture these components. In order to assure a strong domestic supply, the Manufacturing Technology Division identified an initiative to improve the manufacturing capability for this technology by improving or designing manufacturing equipment, and is pursuing this initiative with the Defense Advanced Research Projects Agency.

The active matrix liquid crystal technology must be developed in the United States so that the displays required by the military are available from domestic sources. These programs will develop the manufacturing equipment necessary to establish the domestic manufacturing capability for large-area active matrix liquid crystal displays. The Tri-Service needs for AMLCD cockpit displays are about 45,000 units by the turn of the century. The objective of this project was to establish low-cost color filter manufacturing methods based on improved resin materials.

## Approach

The program approach was to fabricate, evaluate, and demonstrate a small-scale manufacturing process using perflouro-cyclobutane or functionally equivalent resins such as benzocyclobutene.

## Benefits

The benefits are improved product storage stability, lower color filter material cost, and better brightness at equivalent color saturation as compared to present polyimide color filter coatings.

The final report is at DTIC.

## Status

*Complete*
*Start date: March 1995*
*End date: May 1997*

## Resources

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*Electronics*

# Development of Co-Optimized Rapid Thermal Process and a Silicon Deposition Solid-Phase Crystallization Process for Cost Reduced LCD Manufacturing

**Contract Number: F33615-94-C-4449 ALOG Number: 1256**

## Statement of Need

The active matrix liquid crystal technology must be developed in the United States so that the displays required by the military are available from domestic sources. These programs will develop the manufacturing equipment necessary to establish the domestic manufacturing capability for large area active matrix liquid crystal displays (AMLCDs). The Tri-Service needs are approximately 45,000 AMLCD cockpit displays by the turn of the century. Most military display requirements are common with commercial aircraft and, in many instances, the critical component (AMLCD active glass) is common with commercial applications, including portable computers, virtual reality workstations, and television receivers.

The primary objective of this program is to co-optimize the rapid thermal and amorphous silicon deposition processes to yield a solid phase crystallized polysilicon thin film that crystallizes at lower temperatures and is higher in mobility than what is currently available. The specific tasks of the experimentation are to enumerate the a-Si deposition variables along with the rapid thermal processor (RTP) parameters which will contribute to lowering the temperature of RTP solid phase crystallization.

## Approach

This program consists of three tasks: Task I - Liquid-phase Chemical Vapor Deposition (LPCVD) deposited Amorphous-Silicon (a-Si) and RTP; Task II - Plasma-Enhanced Chemical Vapor Deposition (PECVD) films; and Task III - Amorphous-Silicon (a-Si) alloy films with RTP.

## Benefits

The goal of this experimentation is gaining an understanding of the crystallization mechanisms of RTP crystallized amorphous silicon thin films and the interactions which occur with the films deposition processes and then to develop a co-optimized process that is truly manufacturable. The end goal is to transfer this process to volume AMLCD manufacturers.

## Status

*Active*
*Start date: September 1994*
*End date: February 1998*

## Resources

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# EcoBoard: A Tool for the Design of Green Printed Circuit Boards and Assemblies

**Cooperative Agreement Number: F33615-95-2-5548 ALOG Number: 1388**

Electronics

## Statement of Need

The market share of the United States's printed circuit board (PCB) manufacturers has steadily declined from 40 percent in 1980 to 29 percent today, and there is increasing competitive pressure from low-cost foreign producers. The competitiveness of the U.S. PCB and assembly industries is significantly impacted by environmental concerns related to the production, use, and disposal of industry products. In addition, the generation of manufacturing by-products and disposal of outdated or malfunctioning electronics systems are increasing technical and are financial concerns for the Department of Defense. While many companies still rely on end-of-pipe solutions to environmental problems and expend considerable resources to meet regulations generated by governmental agencies, it is clear today that addressing these issues early and rapidly in product development has significant payoffs.

EcoBoard is a computer-based tool for probing the environmental impact of evolving PCB products and processes. EcoBoard will enable a rational assessment of the environmental impact of PCB products and processes throughout the development process. It is based on a holistic approach to the assessment of the environmental impact of systems which account for uncertainties in system parameters and regulations and provides the capability to easily define the scope and the depth of the analysis.

The EcoBoard product is an attempt to address key material and process environmental concerns early in the PCB and PCB assembly development process. The applicability of EcoBoard in the design of real electronic systems and components and the integration of environmental considerations into existing design practices was established through significant demonstrations.

## Approach

This effort was a focused, cost-shared, cooperative industry effort to develop and demonstrate an innovative Design for Environment (DFE) software package called EcoBoard, for the design of green printed circuit boards and PCB assemblies. The active participation of a mainline computer-aided design (CAD) supplier, with the core technology developer and industry users, has lead to a rapidly deployable, customer-focused DFE tool. EcoBoard works in concert with existing design tools, development processes and business practices. It incorporates unique software and analytical features that allow designers to actively consider environmentally sound product and process choices in conjunction with performance and cost considerations. The applicability of EcoBoard in the design of real electronic systems has been established through demonstrations. The greening of a PCB product or process, in terms of lower estimates of life-cycle energy consumption or hazardous waste material generation, has become transparent to a design engineer using EcoBoard.

## Benefits

EcoBoard solves the problem of scope and complexity of environmental analyses, making it practical for designers to assess environmental impact. The critical tradeoff in an environmental analysis is between the time and cost of a comprehensive, detailed assessment and the uncertainty introduced when parts of the life cycle impact are approximated. EcoBoard solves this problem by assessing the strength of links between design choices and environmental impacts. Relatively unimportant links are pruned for the analysis search tree and replaced with a range of values representative of contingencies that would be found in a detailed assessment. EcoBoard accounts for this uncertainty and extends it back to reflect uncertainty in top-level environmental impact metrics.

## Status

*Active*
*Start date: August 1995*
*End date: December 1997*

## Resources

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Electronics

# Electrostatic Printing of High Definition Microstructures for Flat Panel Displays

**Contract Number: F33615-96-C-5104 ALOG Number: 1475**

## Statement of Need

Flat panel display technology must be developed in the United States so that the displays required by the military are available from domestic sources. This program, under the Defense Advanced Research Projects Agency auspices and managed by Air Force Research Laboratory's Manufacturing Technology Division, will help develop the manufacturing equipment, processes and materials necessary to help establish the domestic manufacturing capability for flat panel displays.

The objective of this program was to develop the manufacturing technology for the electrostatic printing of microstructures that consist of metal particles in the submicron to 1 or 2 micron range and glass/ceramic particles in the 1 to 5 micron range. These particles were fused or reflowed together for use in a broad range of display applications. A specific task of the program was the design of a developmental electrostatic press to print these liquid toners onto glass or ceramic substrates in non-contract mode.

## Approach

This effort consisted of designing and building a developmental electrostatic printing press to image fine features on small (approximately 50mm x 50mm) silicon, glass or ceramic plates. A major subset of this effort was the formulation of toners, metallic particle liquid toners and glass/ceramic particle liquid toners for use in the above machine. These were imaged by the developmental press and microstructures produced on the small plates.

## Benefits

This program will help reduce the cost of manufacturing military displays.

## Status

*Complete*
*Start date: July 1996*
*End date: July 1997*

## Resources

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*Contractor:*
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*JDMTP Subpanel:*
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# Fluxless, No Clean, Solder Processing of Components Printed Wiring Board

**Cooperative Agreement Number: F33615-95-2-5511 ALOG Number: 1330**

## Statement of Need

Liquid chemicals in the processing of electrical components, printed wiring boards, and packages are polluting the environment. The single major process using liquid chemicals is soldering. During soldering, liquid fluxes are used to chemically dissolve metal oxides which inhibit soldering. Post-solder cleaning steps use solvents to remove the flux/metal reaction products. The Plasma Assisted Dry Soldering (PADS) process eliminates the need for liquid fluxes and post-solder cleaning, and is widely applicable to many types assemblies and processes. The major objective of the program was to scale up the PADS fluxless soldering process and demonstrate high-volume manufacturing capability on real products. Real products are defined as printed wiring boards in existing systems that are currently fabricated at a production rate (excludes prototype boards).

## Approach

Major manufacturers were contacted to determine their requirements and an industry average was determined for PCB throughput in a manufacturing plant to specify processing requirements for the PADS system. The contractor (MCNC) quantified the performance of the PADS system by measuring the soldering performance and yield of PCB boards that were representative of production techniques. In addition, sufficient attributes were measured to generate a benchmark to compare with future PADS tools. Yield detracting defects were identified and surface analysis was used to provide process understanding. The contractor established and built an experimental testbed for those evaluations that could not be performed on the existing PADS machine. MCNC conducted evaluations of the PADS machine using a representative manufacturer's printed circuit boards wave soldered in their manufacturing facility. Once the process was optimized and stable, MCNC conducted a series of high volume production runs to quantify the highest throughputs, highest yields, and lowest costs. Also, reliability testing was performed on a subset of the products processed with the PADS machine. MCNC installed and evaluated the sample handling automation into the new PADS machine. Other enhancements were identified and incorporated. The PADS process was evaluated to identify compatibility of the new materials/product form factors and soldering processes with the baseline PADS process.

## Benefits

The success of the electronics industry is critical to the economic survival of the United States. Individual companies demonstrated that appreciable cost savings and performance advantages can be obtained through enhanced pollution prevention and waste recycling/disposal activities.

## Status

*Complete*
*Start date: December 1994*
*End date: September 1997*

## Resources

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*Contractor:*
*MCNC*

*JDMTP Subpanel:*
*Electronics*

# Frequency Conversion Material Producibility

**Contract Number: F33615-93-C-4300 ALOG Number: 613**

## Statement of Need

Current Infrared Countermeasure (IRCM) systems for aircraft rely upon expendable decoys (flares) or flashlamp jammers. These systems are effective against first generation infrared missiles, but have limited capability and little growth potential versus current and future generations of missiles. The critical item in a laser system is the mid-infrared laser of which, the non-linear conversion material is the technological long pole. Candidate conversion materials, such as silver gallium selenium (AgGaSe2) and zinc germanium diphosphide (ZnGeP2), have been successfully tested as doublers with CO2 lasers and show much promise. However, the materials are too costly, the yields are low, the quality varies drastically, and the process remains a black art.

The objective of this effort was to develop more repeatable and more cost-effective manufacturing techniques for ZnGeP2 crystals suitable for use in wavelength conversion devices in the mid-infrared spectral region. This effort placed emphasis on the development of processes which control the stoichiometry and composition of ZnGeP2 crystals. Techniques which are compatible with ZnGeP2 for performing surface polishing and thin-film coating were also pursued. In addition, crystal characterization was performed throughout the effort, and the materials quality was demonstrated for optical wavelength conversion for both optical parametric oscillation (OPO) and doubling.

## Approach

There were two awards on this program. The processes in the development cycle that were analyzed include; material selection and mixing, synthesis, seeding, growth, annealing, cutting and polishing, and coating. The material properties were analyzed at various stages in the process with the final test of each production run being a battery of laser frequency conversion tests of the crystal's OPO and doubling characteristics.

## Benefits

The benefits gained from this task are reduced absorption and scattering losses by two orders of magnitude, increased boule size, reduced production time and cost, raised damage levels, reduced thermal lensing, increased thermal conductivity, increased yield, minimized boule to boule variances, and maximized conversion efficiencies. Realizing these goals removes the final obstacle to installing complete infrared missile threat protection on US aircraft.

## Status

*Complete*
*Start date: September 1993*
*End date: November 1996*

## Resources

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*Air Force Funded*

*Contractor:*
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*JDMTP Subpanel:*
*Electronics*

# Green Card: A Biopolymer Based and Environmentally Safe Printed Wiring Board Technology

**Contract Number: F33615-95-C-5509 ALOG Number: 1335**

## Statement of Need

The objective of this program was to develop an alternative printed wiring board (PWB) or "Green Card" that is, by design, easier to reclaim and recycle, and reduces current waste streams.

## Approach

The contractor used a design for the environment/life-cycle analysis type system approach to:

• Replace the fossil fuel epoxy resins used in PWBs with renewable natural polymers derived from plant and wood products, such as lignin, cellulose, and crop oils. The majority of these natural products, while abundantly available, are currently either burned to recover fuel value or contribute to waste stream.

• Fabricate a PWB test vehicle to demonstrate feasibility of using these materials in the manufacturing infrastructure and to verify the reliability of this green PWB.

## Benefits

The materials listed above were used to develop an alternative PWB or "Green Card" that is by design easier to reclaim and recycle, and reduces current waste streams.

## Status

*Complete*
*Start date: March 1995*
*End date: September 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*International Business Machine*

*JDMTP Subpanel:*
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# High Performance Underfill Encapsulant for Low-Cost Flip Chip

**Contract Number: F33615-96-C-5117 ALOG Number: 1520**

## Statement of Need

Direct flip chip attachment of integrated circuits (IC) holds some inherent advantages over conventional packaging of electronics in both defense and commercial applications, such as smaller form factor and higher performance. Overall, there is a pervasive need for better underfill materials and flip chip related cleaning and assembly processes that can enhance the reliability, manufacturability, and repairability of direct chip attach structures. The underfill encapsulant is critical to the reliability of flip chip solder joint interconnects, especially with the flip chip on organic boards, due to the thermal coefficient of expansion (TCE) mismatch between the silicon IC and the organic substrate. The underfill distributes the shear stress evenly over all the solder joints, enhancing the fatigue life of the solder interconnects by typically an order of magnitude. Current underfills suffer from two major drawbacks: long flow time due to the slow capillary action, and an extended cure resulting in long production time and higher cost. Additionally, there is currently no reworkable underfill on the market.

## Approach

This program will be conducted in three phases.

Phase I - Underfill Development - Georgia Institute of Technology
- Development of novel underfills.
- Material processing of no-flow underfill.
- Material testing.
- Documentation on formulations, material properties, progress reports,and technologytransfer.

Phase II - Prototype Scale-Up - National Starch & Chemical/Ablestik
- Identification of organic materials.
- Characterization of underfill composition.
- Manufacturing scaleup.

Phase III - Experimental Validation - National Semiconductor
- Test structures/substrates definition and fabrication.
- Process characterization.
- Prototype assembly.
- Flow-thermal-mechanical modeling of underfilled structures.
- Reliability testing.

## Benefits

This program will yield four key results:

- New classes of underfill materials that have the attributes of fast cure, fast flow, and are reworkable.
- An enhanced one-step flip chip process which shortens the assembly cycle time without compromising reliability.
- Material and processability database complemented with flip chip reliability performance and models of the enhanced underfilling process.
- Commercialized optimized products for wider industry usage.

## Status

*Active*
*Start date: September 1996*
*End date: September 1998*

## Resources

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*JDMTP Subpanel:*
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# Improved Emissive Coatings for Super High Efficiency Color Alternating-Current Plasma Display Panels



**Contract Number: F33615-94-C-4408 ALOG Number: 1207**

## Statement of Need

This program will develop new emissive thin film dielectric coatings to improve both the efficiency and operational characteristics of color alternating-current plasma display panels (AC-PDPs). Theory suggests that the secondary electron emissivity can be improved by up to one to two orders of magnitude.

The primary objective of this program is to improve, in an alternating-current plasma display panel, the efficiency of the emissive layer (which produces secondary electrons from the bombardment of incident plasma ions) potentially by up to one to two orders of magnitude. A specific objective of this program will be to improve the material characteristics of the emissive/protective layer.

## Approach

This program consists of seven tasks. Task I - MgO Crystal and Film Measurements; Task II - MgO Layer Orientation by Ion-Assist; Task III - MgO Layer Orientation by Flow-Through Ion Beam Deposition; Task IV - Cesium Surface Modification Investigation; Task V - Doped MgO Investigation; Task VI - BeO Substitution for MgO; Task VII - Specification of a Large Area, Emissive Coating, Load-Locked Production Coating System; (Option) Task VIII - Delivery of Large Area, Emissive Coating, Load-Locked Production Coating System.

The seven main tasks of this program have been developed to improve the efficiency and operational characteristics of color alternating-current plasma display panels. In addition, Photonics will be involved in supporting these tasks with device performance measurements and prototype fabrication efforts needed to successfully complete each task.

## Benefits

This program will develop new emissive thin film dielectric coatings to improve both the efficiency and operational characteristics of color AC-PDPs.

## Status

*Active*
*Start date: September 1994*
*End date: December 1997*

## Resources

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*Photonics Imaging*

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# Infrared Focal Plane Array Flexible Manufacturing

**Contract Number: F33615-93-C-4320 ALOG Number: 1173**

## Statement of Need

The Electronics Manufacturing Process Improvement (EMPI) program is a multi-year program to enhance the producibility of electronic components and assemblies through enhanced process control using the quality technologies. The primary objective is to promote the application and implementation of statistical techniques for the improvement of electronic manufacturing processes that support the Department of Defense electronics industry sector. Innovative applications of process controls to improve the quality of materials, components, processes, tests, and assemblies used in the manufacture of Air Force systems are being pursued.

Nine contracts were awarded which satisfy the objectives of this program. The contractors will implement the improvements gained as a result of the effort of the EMPI programs. They will also provide a means for transferring the technology that produced those improvements to others within the same industry. The resulting benefits to the Air Force, the contractor, and the industry are in the following areas: improved product reliability, improved process controls, reduced product costs, or reduced cycle time.

The individual programs will rely heavily on the team process and use such techniques as statistical process control (SPC), design of experiments (Taguchi and classical methods), quality function deployment, variability reduction, cause and effect analysis, and flowcharting. Measuring the success of the program will involve establishing a baseline for the application and process selected and then tracking the progress.

The objective of the Infrared Focal Plane Array Flexible Manufacturing (IRFPA/FM) program was to develop and demonstrate the materials, detector processing, sensor electronics, packaging, cryogenics and assembly technology to permit flexible manufacturing of a wide range of array configurations, both staring and scanning. System application categories include: missile seekers, space surveillance, target acquisition sights, search and track systems, man-portable acquisition sights, and threat warning systems. The IRFPA/FM Program was not intended to incrementally improve existing technology. The goal was to demonstrate new concepts in the flexible manufacture of focal plane arrays and focal plane array modules with associated electronics and cryogenics.

## Approach

This program developed and integrated modular processing equipment for HgCdTe detector array fabrication, established a sensor-based computer integrated manufacturing control system, generated smart design tools, implemented manufacturing procedures to reduce the fabrication cycle time of cryogenic readout integrated circuits, developed automated design and assembly capability of infrared focal plane array dewar packages, and performed a baseline, interim, and final production run for staring and scanning infrared focal plane array modules to demonstrate the developed FM capability.

## Benefits

The payoff for this program is a reproducible, affordable, and flexible production capability for IRFPA modules for IRST, missile, munition, and spacecraft applications.

## Status

*Active*
*Start date: September 1993*
*End date: May 1998*

## Resources

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*Contractor:*
*Texas Instruments*

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# Instrument for Rapid Quantitative and Nondestructive Wafer Evaluation



**Contract Number: F33615-96-C-5108 ALOG Number: 1461**

## Statement of Need

The importance of detecting and identifying sub-micron defects is due to the present move by the semiconductor industry to manufacture integrated circuits with feature sizes of 0.5 μm, and in the near future with features sizes of 0.25 μm or less. The latter will require the detection of 2 nm substrate defects to 20 nm sized particles on unpatterned silicon wafers. In addition, the industry is scaling up from 200 mm to 300 mm diameter wafer which will require fewer defects and rapid detection per wafer at all processing stages. To have higher yields, defect data must be processed rapidly in real-time to correct processing problems through statistical process control techniques. The objective of this Phase II Small Business Innovation Research (SBIR) project is to develop a rapid in-process wafer surface defect measurement system that can inspect large surface areas in a non-intrusive, non-contact manner to determine the quality of wafer surface.

## Approach

The approach is to take the Phase I breadboard of the heterodyne laser optical scanning scatterometer and refine it into a commercial product through extensive requirements definition, system design and prototyping and design of experiments evaluation. The system will be beta tested by SEMATECH and other semiconductor manufacturers.

## Benefits

The payoff will be significantly reduced cost and improved quality and reliability of semiconductor devices by identifying defective wafers prior to semiconductor integrated circuit processing.

## Status

*Active*
*Start date: July 1996*
*End date: July 1998*

## Resources

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*SBIR Funded*

*Contractor:*
*Sentec Corporation*

*JDMTP Subpanel:*
*Electronics*

# Integrating People, Products, Processes

**Contract Number: F33615-95-C-5546 ALOG Number: 1360**

## Statement of Need

Funding for the missile sector has declined from a peak of about $9 billion per year in the mid 1980s to about $3 billion per year in fiscal year 1995. Quantities of missiles have declined by considerably more than this factor of three, which indicates a substantial increase in the unit costs of missiles. A major cost-driver is the overhead associated with excess capacity in this industrial sector. The current paradigm of a production facility dedicated to one or two missiles will evolve to an integrated enterprise capable of producing a large family of missiles. The economies of scale are preserved by using the missile mix to compensate for the decline in individual missile quantities. This concept requires an adaptability to change, which is beyond current business practices and technical envelope of manufacturing flexibility. Within this framework of multi-missile manufacturing, innovations and radical process re-engineering need to be implemented. The program challenges industry to demonstrate radically innovative concepts in the tactical missile sector to achieve cost and cycle time savings comparable to those that have been achieved by world-class commercial manufacturers in other sectors. This effort is one of four Defense Advanced Research Projects Agency (DARPA) sponsored programs under the Affordable Multi-Missile Manufacturing program.

## Approach

This program was conducted in three phases. Phase I accomplished: (1) detailed functional design of multi-missile enterprises and associated systems; (2) definition of cost reducing missile design concepts; (3) detailed analysis of the impact on cost of the targeted missile mix as defined by the contractor; (4) identification of technology gaps and enabling tools and technology; and (5) a detailed concept validation plan to be executed in Phase II.

Phase II assessed and mitigated the risks of implementation and refined targeted demonstrations to prove the projected benefits of cost, cycle time, and quality are achievable. Proposed product design and enterprise concepts were validated using a combination of simulation and modeling, design and component-level manufacturing demonstrations, and qualification testing to assess the feasibility of innovative concepts.

Phase III will implement the key product design and manufacturing system and business practice concepts across the target missile mix. Candidate missile seeker demonstrations will prove the capability of implementing the validated design and enterprise concepts in actual multi-missile programs and of achieving the projected cost, cycle time, and quality goals.

## Benefits

This program, when fully adopted and implemented by the missile industry, will impact current and future missile production programs by striving towards the following goals:

- Reducing the unit cost of ongoing missile production programs by 25 percent.
- Reducing the development and production cost for new missiles and major upgrades by 50 percent.
- Reducing the dependence of unit cost on lot size.
- Reducing the development cycle times by at least 50 percent.
- Maintaining or increasing the quality of missile seekers.

## Status

*Active*
*Start date: June 1995*
*End date: January 1998*

## Resources

*Project Engineer:*
*Charles Wagner*
*AFRL/MLME*
*(937) 255-2461*

*DARPA Funded*

*Contractor:*
*Texas Instruments/Hughes Missile Systems*

*JDMTP Subpanel:*
*Electronics*

# Jet Vapor Deposition: A New Environmentally Sound Manufacturing Process

**Contract Number: F33615-95-C-5510 ALOG Number: 1332**

## Statement of Need

Electroplating process waste is a major contributor to ground water pollution nationwide. New regulations in the Clean Water Act will further constrain use of electroplating. The compliance measure will likely raise electroplating costs substantially. Attempts have been made to reduce the inherent hazards in electroplating. Most such attempts have severe drawbacks. For instance, when non-cyanide containing solutions are substituted in electroplating baths used for zinc and cadmium, they result in loss of coating ductility, higher equipment cost (due to the corrosive properties of substitute plating baths), need for better pre-plating cleaning of substrates, and poor end product quality. In addition, even "cleaned up" electroplating processes, using closed loop recycling of plating solutions, represent a hazard, since accidental spills still cause pollution.

The objective of this project was to develop new environmentally safe metallizing processes to replace electroplating in electronics systems manufacturing. The contractor developed and industrialized the jet vapor deposition process to serve as a clean, dry, metallization process for use in manufacturing of microelectronics packaging and interconnect products.

## Approach

The approach was to scale-up, automate, and industrialize the Jet Vapor Deposition (JVD) process so that it can serve as an alternative to electroplating. This was done through:

- Automation of Jet Sources.
- Development of reel-to-reel, automated, modular, production system.
- Demonstration of prototype.

## Benefits

The impact of this project is the development, and commercialization of a new, clean, dry metallization process which produces minimal process waste and no hazardous pollutants. The benefits to the environment of replacing highly polluting electroplating with clean, dry, metallizing processes is widely recognized.

## Status

*Complete*
*Start date: December 1994*
*End date: December 1996*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Jet Process Corp*

*JDMTP Subpanel:*
*Electronics*

# Light Detection and Ranging (LIDAR) Wind Sensor Manufacturability

**Contract Number: F33615-97-C-5145 ALOG Number: 1498**

## Statement of Need

Recent advances in solid-state, diode pumped, coherent lasers which operate at eye-safe wavelengths have made it practical to consider affordable remote wind measurement devices to be installed on military aircraft, airport runways and eventually commercial aircraft. Applications for airborne Light Detection and Ranging (LIDAR) wind sensors include systems which provide a wind-corrected ballistic aimpoint for guns, systems which provide a wind-corrected release point for unguided bombs and missiles, systems which provide wind field measurements for improved airdrop accuracy, systems which measure local air data parameters for avionics and flight control systems, systems which detect wind shear, and systems which measure high altitude winds aloft, aircraft wakes, and clear air turbulence, among other applications. The development of a Doppler LIDAR sensor has enabled the demonstration of these applications and proven the feasibility and advantages of airborne wind field measurement. While these laser sensors are mature enough to consider for production systems, the production of current designs remains labor intensive and requires a high amount of precision hand alignment and tuning.

The program's objective is to: enable the transition of an eyesafe LIDAR wind sensor transceiver to a robust, production ready design which can be employed in numerous applications; to leverage the science and technology Integrated Product and Process Development (IPPD) training program; to demonstrate the application of Design for Manufacturing (DFM) and Rapid Prototyping in the transition of the LIDAR system to production; and to address affordability early in the lifetime of the system by application of IPPD principles.

## Approach

The approach is to address:

- System modularity to enable multiple applications to be satisfied by a single family of components and greatly reduce mean time to repair.
- System reliability to quantify the relationship between individual components and system reliability in order to identify critical reliability areas in the design phase.
- Integrated product/process development to drive down the skill level required for assembly and test of the laser transceiver with a goal of accomplishing assembly and test in less than 36 hours.
- Component cost reduction with a goal of 85 percent commonality of parts among transceiver designs.
- Low cost maintenance which will enable line replaceable modules and eliminate the requirement for a clean room.
- Software selectable system characteristics which would allow the laser characteristics to be tailored to satisfy multiple mission applications.

## Benefits

This project focuses on manufacturability, commonality of components, and affordability/sustainment and will enable multiple applications to be satisfied by a common family of components. It will reduce or eliminate the amount of precision hand alignment and touch labor required in the production and maintenance of a LIDAR transceiver.

## Status

*Active*
*Start date: August 1997*
*End date: August 2000*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*Coherent Technologies Incorporated*

*JDMTP Subpanel:*
*Electronics*

# Low-Cost Alignment-Free Pigtailed Integrated Optic Chip (IOC) for Fiber Optic Gyros

**Contract Number: F33615-96-C-5623 ALOG Number: 1459**

## Statement of Need

Traditional integrated optic chips (IOCs) are fabricated on single crystal lithium niobate (LiNbO3) wafers. The optical waveguide structures are defined by photolithographic methods and with either titanium indiffusion or proton exchange. After coating additional layers and defining electrodes, the LiNbO3 crystal and the fiber interface, the wafers are angle polished and the fibers are cleaved at the appropriate angle. The angle polish requires accurate adjustment before polishing, and the angle cleaving of the fibers is obtained by twisting a fiber before cleaving. All of these steps require well-trained and highly experienced personnel. However, the most labor intensive part is the fiber pigtail alignment: fibers must be aligned to the optical waveguides with submicron accuracy. These alignments are currently done manually, requiring highly skilled workers. The new development of the piezoelectric controlled alignment stages makes the alignment optimization much simpler than the manual adjustment. But the initial coarse adjustments, fiber orientation adjustment, and fiber mounting are still required.

The objective of this research was to develop a class of highly reliable, low cost, fiber pigtailed integrated chips for fiber-optic gyroscope applications. The program explored the use of nonlinear optical (NLO) polymer to replace the traditional single crystalline materials for IOC fabrication, and to eliminate the costly fabrication processes associated with the single crystalline materials. This development included: 1) IOC design based on the performance of the state-of-the-art NLO polymer materials, and 2) a fabrication process leading to significantly reduced cost and improved quality control. The nomenclature nonlinear optical polymer used was a second-order nonlinear optical polymer, which is also known as electro-optic (E-O) polymer.

## Approach

The program approach was conducted in five tasks. Task I investigated the architecture and fabrication technique for the nonlinear optical polymer integrated optic chips. Task II investigated the alignment-free pigtailing method for NLO polymer IOCs. Task III surveyed the material properties and performance of the state-of-the-art NLO polymers, and identified the materials that meet the requirements. During Task IV the contractor chose a preliminary design, analyzed and evaluated the performance of IOCs. In Task V a program plan was developed to predict the cost of the integrated optic chip fabrication, and determine the quality control procedures.

## Benefits

Fiber optic gyros have numerous applications in both the commercial and military markets primarily in the area of navigation in automobiles, airplanes, and ships.

## Status

*Complete*
*Start date: April 1996*
*End date: October 1996*

## Resources

*Project Engineer:*
*Ron Bing*
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*SBIR Funded*

*Contractor:*
*TACAN Aerospace Corporation*

*JDMTP Subpanel:*
*Electronics*

# Low Cost Electrode Fabrication Process for High Definition System Color Flat Panel Displays

**Contract Number: F33615-94-C-4411 ALOG Number: 1208**

## Statement of Need

High resolution color flat panel displays (FPDs) use thin film deposited electrode metallization, typically on the order of one micron thick. Fabrication of such electrodes is a critical high cost process step in the production of FPDs. The number of process steps involved in the fabrication of patterned electrodes generally includes thin film vacuum metallization (e.g., e-beam or sputtering), photolithography, etch, pad printing, and pad firing. The incorporation of flip-chip-on-glass (FCOG) technology into flat panel display manufacturing process adds new requirements and complexity to the metallization system, resulting in additional production processes and cost.

The objective of this project is to develop a low-cost, high resolution, electrode fabrication process based on selective electroplating and/or electroless deposition using electrodes or vacuum deposited seed layer.

## Approach

This effort will be performed in two phases. In Phase I, the contractor will develop vacuum deposited and electroless high resolution seed layers. In the second phase, development of a selective electroplating and electroless metallization system which incorporates compatible photoresist and stripping processes will take place. The metallization systems to be initially evaluated are Cu/Ni/Au.

## Benefits

This new fabrication process will have a very low manufacturing cost, eliminate thick film pad printing and firing, yet be compatible with ultra-high resolution color product and FCOG packaging.

## Status

*Active*
*Start date: September 1994*
*End date: December 1997*

## Resources

*Project Engineer:*
*Charles Wagner*
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*DARPA Funded*

*Contractor:*
*Photonics Imaging*

*JDMTP Subpanel:*
*Electronics*

# Low Cost Flat Panel Display Fabrication

**Grant Number: F33615-94-1-4448    ALOG Number: 1280**

## Statement of Need

The most critical problem in cockpits today is the lack of pilot/crew situation awareness. The present cockpit displays, namely cathode ray tubes (CRTs), have several disadvantages which limit the fusing of the data and presenting situation information to the pilot. Active matrix liquid crystal displays (AMLCDs) are the cockpit designer's choice for replacing CRTs since they are sunlight readable with full color capability. In addition, AMLCDs provide a large viewing area with small instrument depth and do not fail catastrophically rendering the display inoperable.

The active matrix liquid crystal technology must be developed in the United States so that the displays required by the military are available from domestic sources. These programs will develop the manufacturing equipment necessary to establish the domestic manufacturing capability for large area active matrix liquid crystal displays. The Tri-Service needs for AMLCD cockpit displays are approximately 45,000 by the turn of the century. Most military display requirements are common with commercial aircraft and, in many instances, the critical component (AMLCD active glass) is common with commercial applications, including portable computers, virtual reality workstations, and television receivers.

The objective of this effort was to develop an unconventional, low-cost fabrication approach for liquid crystal display flat panels. The new approach is a process employing dry-printing technology and a top-gate self-aligned thin-film transistor.

## Approach

The principal goal in the first year was a demonstration of the lithography of amorphous silicon hydrogen (a-Si:H) and of metal using a mask of laser printer toner. In the second year, thin-film transistors were fabricated using laser printing. In the third year, advanced technology was developed. The scope of this effort includes the following two tasks: a) printing technology, and b) thin-film transistor fabrication.

## Benefits

This process is built upon laser writing technology. This will result in an innovative new process for applying the metallization layer to the sub-plates. This is a lower cost process to achieving the required interconnects to the active elements that form the AMLCD flat panel.

## Status

*Complete*
*Start date: July 1994*
*End date: July 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*University of Alabama*

*JDMTP Subpanel:*
*Electronics*

# Low Cost Flip Chip

**Contract Number: MDA972-95-3-0031  ALOG Number: 1602**

## Statement of Need

The continuing evolution of electronic products toward lower cost, smaller form factor, lower weight and higher performance capabilities is focusing attention on the need to simplify and reduce integrated circuit (IC) packaging. Realistically, existing packages are performance and cost limiters whose presence is necessitated chiefly as space transformers, mechanical protection and transport vehicles. Throughout the historical development of IC-based microelectronics, the major gaps between the feature sizes of silicon, packages and PC boards have been to force the issue to a resolution. That has now changed, and there is a growing desire to take the next logical step — elimination of the package — and move to direct chip attach (DCA) of bare silicon die on the product board.

## Approach

This program is structured around a vertically integrated consortium led by National Semiconductor Corporation. Collectively, these members possess the resources to put in place a fabrication capability for low cost flip DCA, ranging from chip design through end product assembly. Equally important, they command a wide range of military and commercial markets. The customer products will drive the technology developed by this consortium.

## Benefits

The team will drive technology development and the economies of high-volume manufacturing to reduce direct chip attach costs to the point where broad market acceptance will be assured. A major goal of this project is to develop an alternative to high-temperature, high lead content evaporated solders by providing a complete low cost flip chip DCA product.

## Status

*Active*
*Start date: August 1995*
*End date: March 1998*

## Resources

*Project Engineer:*
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*TRP Funded*

*Contractor:*
*National Semiconductor Corporation*

*JDMTP Subpanel:*
*Electronics*

# Low Cost, High Performance, Low Temperature Co-fired Ceramic-on-Metal Substrates for Mixed Signal Modules

Electronics

Electronics

**Cooperative Agreement Number: F33615-96-2-5105 ALOG Number: 1528**

## Statement of Need

The focus of this program is on packaging technologies for mixed signal applications, particularly those applications which combine wireless communication with computing in a compact form factor. One of the challenges of mixed signal packaging is insuring adequate isolation of low level analog signals in close proximity to high speed digital signals. This can be accomplished by incorporating filters into the multilayer substrate itself.

## Approach

The objective of this program is to develop the capability to fabricate buried passive components directly into low temperature co-fired ceramic (LTCC) substrates, develop design kits for the buried component technology and to transfer that technology to a high volume substrate manufacturer.

## Benefits

By developing the technology to incorporate buried passive devices and filters directly within a multi-layer LTCC-M substrate, very high mixed signal device densities can be achieved in very small form factor packages. Low cost, high performance, mixed signal devices are becoming increasingly important to the DoD as it becomes necessary to distribute more information directly to the individual soldier, munition, or weapon system.

## Status

*Active*
*Start date: September 1996*
*End date: September 1998*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*David Sarnoff Research Center*

*JDMTP Subpanel:*
*Electronics*

# Manufacturing Technology for Multi-Band Gap Solar Cells

**Contract Number: F33615-95-C-5561 ALOG Number: 1465**

## Statement of Need

The cost of a launch vehicle can be as much or more than the satellite it is putting into space. Reducing the launch vehicle's size can cut overall costs by 200 to 300 percent. Even if the launch vehicle size cannot be reduced, a lighter satellite equates to larger amounts of station-keeping propellant loaded aboard, which means a longer service life for the satellite. The objective of this program is to produce monolithic III-V multi-junction solar cells grown on silicon or germanium substrates for space applications. The goal is to escalate yield, increase efficiency, and reduce cost by improving the manufacturing processes of these cells. If the program power efficiency and cost goals are achieved, a 14 percent cost savings per watt can be expected.

## Approach

This effort will build upon the work done by Phillips Laboratory in developing multi-junction technology, and upon Wright Laboratory Manufacturing Technology Division's single junction gallium arsenide (GaAs) solar cell program and the gallium arsenide-on-germanium solar cell program. The program will have three phases. Phase I will define a baseline to establish current capabilities. In Phase II, the contractor will refine the metal organic chemical vapor deposit growth process, among others, using design of experiments and other quality engineering techniques. In Phase III, the contractor will validate the process improvements with a final validation production run.

## Benefits

The benefit of this effort will be the establishment of manufacturing processes for affordable, power efficient, space-qualified multiband gap solar cells.

## Status

*Active*
*Start date: September 1995*
*End date: September 1998*

## Resources

*Project Engineer:*
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*(937) 255-2461*

*Air Force Funded*

*Contractor:*
*Spectrolab Inc.*

*JDMTP Subpanel:*
*Electronics*

# Manufacturing Technology for Multi-Band Gap Solar Cell Array

**Contract Number: F33615-95-C-5508 ALOG Number: 1278**



## Statement of Need

The cost of the launch vehicle can be as much or more than the satellite it is putting into space. Reducing the size of the launch vehicle can cut costs by 200 to 300 percent. Even if launch vehicle size cannot be reduced, a lighter satellite means more station-keeping propellant can be loaded aboard which means a longer service life for the satellite. The objective of this program is to enable the production of monolithic III-V multi-junction solar cells grown on silicon or germanium substrates for space applications. The goal is to improve the yield and efficiency, and reduce the cost of the manufacturing processes used in producing these cells while increasing the size of the solar cells to the sizes available in single junction solar cells.

## Approach

This effort will build upon the work done by Phillips Laboratory in developing multi-junction technology, and upon the Manufacturing Technology Division's work with single junction germanium arsenide (GeAs) Solar Cells and gallium arsenide on germanium (GaAs-on-Ge) Solar Cells. The program will have three phases. Phase I will define a baseline to establish current capabilities. In Phase II the contractor will refine the growth and other processes using Design of Experiments and other quality engineering techniques. In Phase III the contractor will validate the process improvements with a final validation production run.

## Benefits

This program will allow the development of more efficient power for space satellite systems (more power for less weight). This will lead to a smaller satellite requiring a smaller and cheaper launch vehicle, at major cost savings.

## Status

*Active*
*Start date: September 1995*
*End date: March 1999*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*TECSTAR Corp.,*
*Applied Solar Energy Division*

*JDMTP Subpanel:*
*Electronics*

# Manufacturing Technology for Tactical Grade Interferometric Fiber Gyroscopes

**Contract Number: F33615-93-C-4321 ALOG Number: 405**

## Statement of Need

Future missile, munition, and tactical aircraft systems will require low-cost inertial and navigational sensors. Interferometric Fiber Gyroscopes (IFOG) subsystems offer the potential of improved reliability, reduced cost, and design flexibility over current mechanical and ring laser gyro subsystems. High IFOG costs were originally driven by the fact that fabrication processes required extreme accuracy and assembly was extremely labor intensive. Improved manufacturing processes were required to reduce IFOG costs originally estimated at $6,000-$7,000 per axis. The objective of this program was to establish the manufacturing processes and supplier base required to produce tactical grade IFOGs at less than $1,000 per axis, with a goal of $500 per axis.

## Approach

The purpose of the program was to accelerate the integration of IFOG technology into tactical missile guidance and aircraft navigation systems. Goals include reduced unit cost, improved manufacturing processes, technology transfer, and an enhanced, flexible industrial base. Objectives of the program were met primarily through continuous process improvement techniques (Design of Experiments, process and costs models, statistical process control and process capability measurements) in conjunction with a teaming arrangement with the component suppliers.

## Benefits

Benefits include a greater than 90 percent cost reduction of IFOGs for applications in aircraft navigation and missile guidance subsystems; the establishment of improved and controlled manufacturing processes; and direction to and enhancement of the IFOG industrial base.

## Status

*Complete*
*Start date: September 1993*
*End date: January 1998*

## Resources

*Project Engineer:*
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*AFRL/MLME*
*(937) 255-2461*

*Air Force Funded*

*Contractor:*
*Litton Corporation*

*JDMTP Subpanel:*
*Electronics*

# Method of Producing Advanced Printed Wiring Boards Using the Technology of Thermal Spraying



**Contract Number: F33615-97-C-5131 ALOG Number: 1543**

## Statement of Need

Emphasis on manufacturing environmental friendliness has the Department of Defense and the suppliers of commercial printed wiring boards investigating alternative methods of depositing copper thin films in a more controllable and cost effective manner. Today's interconnection technology is primarily dependent on plating technology to provide electrical interconnections on the surface and in the through-hole for z-axis interconnections between the layers of a multilayer printed wiring board. Plating bath waste and water contamination requires treatment and proper disposal which has severe environmental and economic consequences in high volume manufacturing. Novel, more environmentally friendly, thin film metalization techniques are necessary to fabricate intricate copper conductors necessary for increased performance and reliability required in newer, finer featured packaging structures. The technology of thermal spraying will be investigated for developing an improved, more environmentally friendly, copper thin film metalization process. Thermal spraying is a process wherein molten metal droplets are sprayed on a substrate.

## Approach

Thermal spray variables will be investigated and electrical, mechanical, and adhesive properties of the resultant films on organic laminates will be characterized. Three masking processes for direct pattern delineation will also be evaluated for compatibility with the thermal spray process. Cold spraying of the copper conductor traces will be investigated with Sandia National Laboratory, to determine feasibility of the technology.

## Benefits

Copper plating is the backbone of today's printed wiring board manufacturing industry for both military and commercial suppliers. These sophisticated interconnect structures are the foundation of a worldwide market of $18 billion in commercial electronics. Newer thin film copper metalization techniques like thermal spraying will be more environmentally friendly, while providing a more reliable, more cost effective, higher density interconnect structure.

## Status

*Complete*
*Start date: May 1997*
*End date: November 1997*

## Resources

*Project Engineer:*
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*(937) 255-2644*

*SBIR Funded*

*Contractor:*
*Thermal Spray Technologies Incorporated*

*JDMTP Subpanel:*
*Electronics*

# Modeling for Sensor-Based Semiconductor Process Control

**Contract Number: F33615-95-C-5543 ALOG Number: 1380**

## Statement of Need

Many processes in the semiconductor industry require precise control of temperature. Therefore, an accurate model of the process that includes all the major physical parameters that govern the behavior of the system would be a valuable tool. In addition, there is no commercially available, semiconductor fabrication equipment that uses model-based feedback control systems for adjusting process inputs to compensate for variations and disturbances. For instance, rapid thermal processing (RTP) chambers have not taken off as expected due to temperature uniformity and repeatability problems. These problems can certainly be resolved with a model based feedback control system. The goal of this Phase II Small Business Innovation Research (SBIR) program is to create a comprehensive graphical modeling tool for thermal systems and develop control design techniques to address a broad class of thermal problems.

## Approach

The objective of this program is twofold: 1) develop the techniques and software tools needed to create detailed physical models of the processes typical of semiconductor fabrication; and 2) develop sensing and control algorithms based on the physical models. The program will:

- Develop a graphical model building software tool
- Create techniques for developing advanced multivariable model-based control systems
- Build a graphical user interface to make the software easy to use
- Demonstrate the modeling tool by developing a physical model of a commercial RTP chamber
- Develop and demonstrate a model-based multivariable real-time control system for the RTP chamber
- Develop a generic thermal modeling prototype commercial software product

## Benefits

This program will:

- Eliminate the need for intimate knowledge of modeling and control design algorithms
- Allow rapid repetitive design iterations
- Enable seamless interaction with a real-time implementation environment
- Provide capabilities not currently available with commercially available modeling or Computer Aided Control Engineering (CACE) tools

## Status

*Complete*
*Start date: September 1995*
*End date: September 1997*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*Integrated Systems Inc.*

*JDMTP Subpanel:*
*Electronics*

# Permanent Dry Film Resist for Printed Wiring Board Process Simplification and Environmental Benefit

**Contract Number: F33615-95-C-5504 ALOG Number: 1343**

## Statement of Need

The capacity to produce quality printed wiring boards (PWBs) is an evolutionary step in moving the industry toward better, lower cost, lower environmental impact processes. By eliminating process steps, particularly at the back end of the process where the PWB already has significant value added to the materials, there is inherently less cost and fewer chances for damage and loss of partially completed boards. This is not true of the oxide process which is notoriously difficult to control and often causes delamination defects in pressed multi-layers around drilled through-holes thus causing scrapped boards of high value and increasing waste. Using a resist of consistent composition and adhesion will eliminate this problem. The use of a permanent resist that effectively eliminates stripping and the oxide treatment and maintains or improves inner-layer adhesion, particularly around the through holes will be a widely accepted technology. This project developed a drop-in change, with no requirements for new equipment, process solutions, or additional materials. It represents a new approach in pollution prevention for the PWB industry, by using a different process to eliminate pollution, rather than simply using less of existing materials.

## Approach

Task I, Specifications and Test Vehicle Selection, defined the specifications for the resist and process of use and included choosing or developing a suitable test vehicle(s).

Task II, Understanding the Technology, was a development of the understanding of the parameters that exist in the process and materials including not only the resist, but also the copper and conventional dielectric bond-ply materials to which the resist must adhere during and after construction of conventional multilayer PWBs.

Task III, Semiworks Test of Process and Materials Elements, established a semiworks line to allow for optimization of the process parameters and generation of simple test parts.

Task IV, Scale-up Process, transferred the process to manufacturing participants where necessary adjustments to the process were made to make it acceptable in a manufacturing scale mode. In addition, the coating process was scaled up and commercial quality resist was manufactured while release tests and finishing tests are also completed.

Task V, Test and Manufacturing Demonstration, geared up to large scale manufacturing using the process and materials for additional tests of both bare and assembled boards, including compatibility with automated optical inspection.

Task VI, Dissemination, was the dissemination of the test data, sample parts, and project reports using several trade associations as forums for the results, as well as a road-show to demonstrate the process and parts testing on a manufacturing site.

## Benefits

This project eliminated excess production steps, while requiring no capital expenditures thus reducing production costs for conventional subtractive inner layers of multilayer printed wiring boards. It enhanced the ability of automatic optical inspection (AOI) to more accurately test bare panels thus reducing scrap losses due to inaccurate inspection. Most significantly, it reduced hazardous waste attributable to resist stripping and more importantly to the steps involved with oxide treatment for copper adhesion to inner-layer prepreg in multi-layer boards.

## Status

*Complete*
*Start date: January 1995*
*End date: September 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*EI DuPont*

*JDMTP Subpanel:*
*Electronics*

# Precision Thick Film Technology for 100 Percent Yield of Large Area High Resolution Color Alternating-Current Plasma Display Panels

**Contract Number: F33615-94-C-4406 ALOG Number: 1206**

## Statement of Need

A key problem in printing a large area, inorganic glass dielectric film, is that there is presently no non-contact method to measure either the film thickness or uniformity prior to firing the part. Thus, there can be no in-process control to dynamically adjust the screen printer for each substrate's unique characteristics in order to achieve 100 percent yield. The situation is even worse for technologies that require printing prior to firing as the statistical variation worsens with each layer.

The primary objective of this program is to develop a low-cost precision thick film screen printing manufacturing process capable of producing high resolution, full color alternating-current plasma display panels (AC-PDPs) with a yield of 100 percent. This program shall develop an integrated screen printing manufacturing process capable of achieving both large area print uniformity and thickness control in a flat-panel display (FPD) manufacturing operation. The technology being developed is generic in nature and will benefit other FPD/electronic devices.

## Approach

This program consists of five tasks with an optional sixth task being performed in year two:

- Task I - Glass Plate Uniformity.
- Task II - Film Thickness Measurement by Weight.
- Task III - Fabrication of 10-inch Screen Printing.
- Task IV - Development of wet or "green" dielectric thickness non-contact measuring sensors.
- Task V - Development of integrated flat-panel display (FPD) manufacturing model software.
- Optional Task VI - Development of a production measuring machine for large panels designed to make non-contact thickness measurements on the glass panel.

This is a development effort which will conclude with integrated FPD thick film screen printer manufacturing model software.

## Benefits

This program will develop new production equipment, novel sensors, and innovative software, for total in-process quality feedback control in the thick film process loop manufacturing cluster. An order of magnitude improvement in screen printed film quality is expected, resulting in color AC-PDPs that rival the performance of active matrix liquid crystal displays, but at greatly reduced cost.

## Status

*Active*
*Start date: September 1994*
*End date: December 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Photonics Imaging*

*JDMTP Subpanel:*
*Electronics*

# Prototype Development of a Very Large Area, High Performance Microlithography Tool

Electronics

**Contract Number: F33615-92-C-5805    ALOG Number: 445**

## Statement of Need

The most critical problem in cockpits today is the lack of pilot/crew situational awareness. The present cockpit displays, namely cathode ray tubes (CRTs), have several disadvantages which limit the fusing of the data and presenting situation information to the pilot. Active matrix liquid crystal displays (AMLCDs) are the cockpit designer's choice for replacing CRTs since they are sunlight readable with full color capability. In addition, AMLCDs provide a large viewing area and are fail soft with small instrument depth.

The active matrix liquid crystal technology must be developed in the United States so that the displays required by the military are available from domestic sources. These programs sh all develop the manufacturing equipment necessary to establish the domestic manufacturing capability for large area active matrix liquid crystal displays. The Tri-Service needs for AMLCD cockpit displays is approximately 45,000 by the turn of the century. Most military display requirements are common with commercial aircraft and, in many instances, the critical component (AMLCD active glass) is common with commercial applications including portable computers, virtual reality workstations, and television receivers.

The specific objective of this program is to construct a full-scale prototype of a large area microlithography tool capable of imaging glass substrates up to 500 mm x 600 mm square at approximately threefold increase in imaging throughput rates as compared to any currently available large area microlithography tool.

## Approach

This effort includes the development of the following subsystem components: 1) a 500 mm by 600 mm linear stepping, motor based X-Y stage subsystem; 2) a high-power illumination subsystem; 3) a novel imaging subsystem capable of image scale adjustment of ≤ 100 ppm and image resolution of ≤ 3um; 4) an automatic calibration metrology and control subsystem; 5) an automatic, high-speed substrate alignment subsystem; 6) an automatic reticle storage and handling subsystem; 7) an automatic, high-speed, externally-interfaceable substrate handling system; 8) an environmental control subsystem; and 9) job setup and execution control software.

## Benefits

This project will provide a three-fold increase in throughput and a Production Substrate Handling System for large displays (24" x 20").

## Status

*Active*
*Start date: February 1992*
*End date: September 1998*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*MRS Technology*

*JDMTP Subpanel:*
*Electronics*

Electronics

Electronics

# Real-Time FT-IR Diagnostics and Control of Semiconductor Fabrication

**Contract Number: F33615-95-C-5545 ALOG Number: 1426**

## Statement of Need

Recent developments in microelectronics manufacturing have emphasized a high flexibility concept, including single wafer processing in cluster tools, sensor-based, closed loop process control, and factory automation. Although these concepts have already been demonstrated, in order for the industry to fully benefit from the implementation of these concepts, continuing advancements are needed in the area of modeling for real-time process control. Typical single wafer processes require tight control for silicon device fabrication and include chemical and physical vapor deposition, plasma processes, and rapid thermal processes. The objective of this project was to develop models for sensor-based control of single wafer silicon microelectronics processes.

## Approach

This project includes verification of models with actual manufacturing processes, further modification of models as necessary, and planning for the implementation of the models into production.

## Benefits

Single wafer processes have been developed for semiconductor processing which has both military and commercial application. Single wafer processing is ideal for low volume production (military and commercial), such as for application specific devices, prototypes, and large diameter wafers, and is also scalable for high volume production, as is typical for commercial commodity parts. Sensor-based process control and modeling optimize the quality and throughput of these processes.

## Status

*Active*
*Start date: September 1995*
*End date: January 1998*

## Resources

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*SBIR Funded*

*Contractor:*
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*JDMTP Subpanel:*
*Electronics*

# Real-Time Whole Wafer Thermal Imaging for Semiconductor



**Contract Number: F33615-97-C-5134 ALOG Number: 1533**

## Statement of Need

The production of <0.5 mm of very large scale integrated (VLSI) silicon integrated circuits and III-IV semiconductor heterojunction and quantum well devices requires the capability to measure and control the across-wafer temperature to ± 1° C at temperatures ranging from 150° C to 1100° C depending on the type of fabrication processes used. Currently either thermocouples or optical pyrometers are used for measuring the wafer temperature. Thermocouples in contact with the wafer provide the actual temperature of the wafer only in the region of the contact point. While fairly reliable, thermocouples suffer from slow response time, and their lifetime is inversely proportional to the process temperature. Optical pyrometers, on the other hand, respond rapidly, but the measured temperature can be unduly influenced by variations in the wafer emissivity which is a function of the number and type of layers on the wafer. In addition, the reliability of pyrometers is of concern. For the most part, these techniques are also restricted to measuring the temperature at a point or small region of the wafer. The objective of this project is to develop a fast polarimetric imaging radiometer capable of producing whole wafer temperature maps with accuracy (even when the emissivity may be drifting), temperature dependence and spatially varying.

## Approach

This project will be performed in five tasks:
Task 1 - Obtain and characterize test samples.
Task 2 - Construction of test reactor.
Task 3 - Instrument construction.
Task 4 - Calibration and shakedown.
Task 5 - Validation.
Task 6 - Phase II design study.

## Benefits

An accurate and reliable in situ whole-wafer temperature measurement technique will have an immediate commercial market in temperature monitoring and control for a wide variety of thermal processing technologies such as rapid thermal processing, molecular beam epitaxy and metallo-organic chemical vapor deposition.

## Status

*Active*
*Start date: April 1997*
*End date: December 1997*

## Resources

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# Revolutionary Environmental Manufacture of Printed Wiring Boards with Electroless Plating and Conductive Inks

**Contract Number: F33615-95-C-5505 ALOG Number: 1344**

## Statement of Need

Current manufacturing processes used to make printed wiring boards (PWBs), a fundamental component of all electronics products, produce a waste stream largely generated during the imaging, etching, and plating processes. Thus, to produce four pounds of product, 46 pounds of waste is produced (not including water waste), approximately 85 percent of which is hazardous. This is the largest component of waste generated in electronics manufacture, excluding semiconductors. The cost of waste treatment (estimated at over $140 million for 1990 for the major merchant PWB manufacturers) and the additional regulatory burden of record keeping, manifesting, and chemical inventory reporting have placed a very significant economic burden on the PWB manufacturers in this country.

The objective of this project was to demonstrate a low cost, high performance, revolutionary additive approach to the manufacture of printed wiring boards for all but high power applications, using photo-imagable, solvent-free dry-film dielectrics and conductive inks that will reduce hazardous waste production by 100 percent, water use by 75-90 percent, nonhazardous waste production by 50 percent, and energy use by 75 percent.

## Approach

The first step was development of the specifications for the photo-imagable dielectric. Test material was used to develop parameters for a manufacturing process of use and test circuits made in a prototype facility. Health, safety and environmental parameters were verified, and parameters for the process of use were optimized. The photo-imagable dielectric was manufactured in quantities large enough to test the suppliers' ability to test the material in a production facility. Boards were fabricated under production conditions using a commercial design which was tested for physical, electrical, mechanical, and environmental properties.

## Benefits

The material used is benign to the environment and can serve as biomass in the biological treatment section of most sewage treatment plants. The use of such a photo-imagable dielectric dry film (PDDF) eliminates the need for a separate dielectric and clad metal layer that requires either etching or a combination of plating and etching to produce a circuit, and for the removable resist used to define that circuit. The cleaning steps required for resist adhesion, cleaning required for plated metal to base metal adhesion, and cleanup after the various steps were all eliminated. These steps accounted for as much as 90 percent of the water usage in the PWB process.

## Status

*Complete*
*Start date: January 1995*
*End date: September 1997*

## Resources

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*Contractor:*
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# Rugate Coating Producibility

**Contract Number: F33615-93-C-5317 ALOG Number: 411**

## Statement of Need

Optical systems that operate at visible and infrared wavelength are used for surveillance and target acquisition, tracking, and designation. These systems incorporate optical rejection and mission filters, antireflection coatings, and dichroic layers which can have demanding optical requirements. Rugate coatings can be used to fabricate optical components that meet these demanding requirements. However, the producibility of these coatings has not been established. Recent investigations indicate that rugate coatings have potential application in many weapon systems. These coatings also have potential applications for eye protection.

The Rugate Coating Producibility task established a production capability for rugate coatings that demonstrated enhanced yield, increased throughput, process scalability, and reduced costs. In addition, emphasis was placed on transferring the in-situ monitoring techniques and process methodology used to manufacture rugate coatings to other manufacturers of optical, microelectronic, microwave, and optoelectronic thin film devices.



## Approach

The task included three production runs to demonstrate increased yield and throughput and reduced cost for rugate components. A production run was completed to establish a baseline and intermediate and final production runs demonstrated the progress made during the task. A specification for one rugate demonstration component was established at the beginning of the task and remained unchanged during the course of the program. During each production run the contractor fabricated this device and measured process improvements against the baseline run. Second and third optical components were fabricated during the intermediate and final production runs.. The contractor demonstration component was designed for a purpose other than narrow band rejection and replaced a non-rugate component fabricated by conventional deposition methods. The purpose of producing this device was to demonstrate the benefits of rugate coating process methodology for fabricating components designed to replace conventional optical components.

## Benefits

The task established the capability to reproducibly fabricate affordable, high performance rugate coatings. The task goals were to demonstrate a 50 percent reduction in the number of components rejected, a 50 percent reduction in component cost, and a 500 percent increase in component throughput.

## Status

*Active*
*Start date: September 1993*
*End date: December 1997*

## Resources

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*Hughes Company*

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# Self-Orienting Fluidic Transport Assembly

**Contract Number: F33615-96-C-5111 ALOG Number: 1448**

## Statement of Need

Flat panel display technology must be developed in the United States so that the displays required by the military are available from domestic sources. This program, under the Defense Advanced Research Projects Agency auspices and managed by Air Force Research Laboratory's Manufacturing Technology Division, will help develop the manufacturing equipment, processes and materials necessary to help establish the domestic manufacturing capability for flat panel displays.

The primary objective of this program was to develop a process for the manufacture of high information content displays by fluidic self assembly. The specific objective of this program was the development of a process for economical high volume manufacture of the active matrix portion of an active matrix liquid crystal display using fluidic self assembly of small foundry silicon blocks onto substrates.

## Approach

Self-Orienting Fluidic Transport (SOFT) Assembly will create high performance displays, primarily due to the initial fabrication and testing of each element before final assembly. This was a three phase program with Phase I being the basic program and where Phases II and III were options 1 and 2, respectively. Phase I focused on laboratory demonstration of the processes involved. The program developed a complete, scalable and manufacturable prototype process for the manufacture of active matrix assemblies by fluidic self assembly of foundry single crystal silicon, suitable for further processing into active matrix liquid crystal displays using conventional liquid crystal display technology.

## Benefits

This technique exploits a fundamental building block to construct a new display. Different sizes and shapes can now be fabricated using the same basic technology to meet the need of low volume custom displays for the military market. This effort will result in higher performance and lower cost of military displays.

## Status

*Complete*
*Start date: September 1996*
*End date: September 1997*

## Resources

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# Smart Electron Cyclotron Resonance Plasma Etching

**Contract Number: F33615-92-C-5972 ALOG Number: 412**

## Statement of Need

Currently, problems with the dry etch processes and molecular beam epitaxial (MBE) growth processes reduce the manufacturability and increase the cost of advanced III-V compound semiconductor devices. The objective of this program was to develop and demonstrate a sensors-based, closed-loop control system integrated with electron cyclotron resonance (ECR) plasma etching equipment. This "smart" ECR plasma etching system was used to demonstrate reduced surface damage and improved selectivity, uniformity, and depth control over the etching of III-V engineered thin film structures. Emphasis was placed on transferring the techniques and process methodology of the "smart" ECR etching process to a manufacturing pilot line for full-scale demonstration of the benefits and improvements in process yield and reduced production costs.

## Approach

This program consisted of three phases. In Phase I, the contractor determined and developed the sensors and control system methodology for a reproducible, single-step plasma etching process. This dry etch process is capable of meeting the etching requirements for advanced III-V engineered thin-film structures such as heterojunction bipolar transistors or high electron mobility transistors.

In Phase II, the contractor designed, developed, and integrated a suit of robust sensors and an adaptive process control system to an ECR plasma etcher. An engineering prototype ECR plasma etching system was configured to be suitable for use in a manufacturing environment. The contractor performed feasibility studies and established the production worthiness of this fully automated ECR plasma etching system.

In Phase III, the contractor transitioned the "smart" ECR plasma etch system to a manufacturing pilot line for demonstrating the benefits and improvements in process yield and reduced production costs of advanced III-V engineered thin-film structures. The "smart" ECR plasma etcher performance in improving the throughput, yield, and cost transistors fabrication was demonstrated and evaluated.

## Benefits

Benefits include shorter cycle time for processing base contact of engineering thin film structures, and versatile, robust dry plasma etching capability for semiconductor processing.

## Status

*Complete*
*Start date: August 1992*
*End date: April 1997*

## Resources

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*JDMTP Subpanel:*
*Electronics*

# Solder Jetting for Electronics Manufacturing

**Cooperative Agreement Number: F33615-97-2-5120 ALOG Number: 1526**

## Statement of Need

Future Department of Defense systems will require low-cost printed wiring boards (PWBs) populated with multiple types of electronic component packing. Soldering electronic components to various targeted surfaces is a key manufacturing process used in all manner of avionics and Department of Defense ground systems. One key area that can reduce the sensitivity of production costs to shrinking volume is to eliminate the start-up costs to setting up an automated soldering dispensation system. Solder jet processing can eliminate the masks, screens, and other start-up requirements with a typical production solder application system.

## Approach

The goal of this effort is the development of advanced solder deposition equipment for the electronics manufacturing industry. The basis for solder jet printing is demand-mode ink-jet printing. A droplet is created only when it is desired in demand-mode systems. Demand-mode ink-jet printing systems produce droplets that are approximately equal to the orifice diameter of the droplet generator. Solder jet-based equipment will produce and place molten solder droplets, 25-125 μm in diameter, at rates up to 2,000 per second, making it suitable for high throughput, low cost packaging and assembly of the high density commercial and military electronics.

## Benefits

Solder jet based deposition will be low cost (no tooling required), non-contact, flexible/data-driven (no masks or screens are required because the printing information is created directly from computer aided design information and stored digitally), and environmentally friendly (it is an additive process with no chemical waste).

## Status

*Active*
*Start date: March 1997*
*End date: September 1998*

## Resources

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*Contractor:*
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*JDMTP Subpanel:*
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# Strategic Packaging for Single & Multi-Chip Modules Using Very Small Peripheral Arrays



**Cooperative Agreement Number: F33615-96-2-5110    ALOG Number: 1468**

## Statement of Need

The primary objective of this program was to design, develop, and produce a family of very small peripheral array-based semiconductor packages to handle devices that require a high I/O pin count.

## Approach

This project was proposed as a three-year effort. The Defense Advanced Research Projects Agency funded the first year of the effort with an option to fund the second year, depending on the results of Phase I. The first year effort completed the design, development and testing of the initial single chip package technology, developed automated manufacturing processes that provide a significant reduction in assembly cost, and demonstrated fully automated chip placement and wirebonding as well as an encapsulation process. The contractor inserted a very small peripheral array (VSPA) into a real application and measured user acceptance and field reliability.

The results will be used to define the set of VSPA products that can be manufactured in a cost-effective environment and be priced competitively with current packaging technologies available in the marketplace.

## Benefits

This program demonstrated the viability of very small peripheral arrays and ensured the reliability of the technology for use in applications that require a high I/O pin count. The VSPA technology is an alternative packaging concept that reduces the board space requirements and can be easily soldered in place as an alternative to more traditional plastic packages. This technology provides a high I/O pin count in a small space while handling the inherent thermal load efficiently.

## Status

*Active*
*Start date: September 1996*
*End date: March 1998*

## Resources

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# Tertiary Recycling of Electronic Materials

**Contract Number: F33615-95-C-5507 ALOG Number: 1345**

## Statement of Need

No effective recycling process is currently available for organic-based waste materials generated in processing electronics or for obsolete electronic assemblies, components, packaging, and cables because electronic assemblies consist of exceedingly complex mixtures of numerous types of plastics, metals, and ceramics. Millions of pounds of these materials are land-filled each year. Because many of these materials contain toxic or potentially toxic heavy metals and chemicals, scrapping of such large volumes represents a tremendous potential for hazardous waste.

The objective of this program was to investigate the suitability of an economical tertiary (producing chemicals or fuels) recycling process for recycling of scrap electronic materials. This process can convert a wide variety of polymers and composites into low molecular weight hydrocarbons at temperatures below 200 degrees Celsius. The hydrocarbons can then be reused as chemicals, fuels, or monomers. Metals, glass, ceramics, and fillers are separated from the hydrocarbons for reclamation.

## Approach

Preliminary feasibility studies on plastics, composites, and sample electronic components show that the conversion process can remove polymers from mixed waste streams as low molecular weight hydrocarbons. The hydrocarbons can then be used as chemical intermediates. Metals can be re-smelted, fibers reclaimed for reuse as reinforcements, and ceramics and fillers added to low-cost plastics or added to brick or cement formulations.

In this project, the contractor developed the technical and market data necessary to demonstrate the low-temperature catalytic conversion process for the recycling of scrap electronic materials. Separation processes for the solid residues were developed and design data for large-scale systems was generated. A medium-scale system was fabricated and demonstrated and the economical feasibility of this process was assessed.

## Benefits

Successful deployment of tertiary recycling technology for reclaiming scrap electronic materials will have numerous benefits for the environment, the electronics industry, and the Department of Defense. These systems will provide a means of economically recovering virtually all of the raw materials that make up electronic assemblies and packaging. This will prevent their introduction into landfills, thus, eliminating placing hazardous and toxic wastes into the environment. Because this process can be applied to most or all electronic materials currently in use, no extensive redesign for recycling is required.

## Status

*Complete*
*Start date: December 1994*
*End date: September 1997*

## Resources

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*DARPA Funded*

*Contractor:*
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*JDMTP Subpanel:*
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# Whole Wafer Thermal Measurement by Means of Laser Ultrasound

**Contract Number: F33615-97-C-5133   ALOG Number: 1535**

## Statement of Need

The production of $<$0.5 mm of very large scale integrated (VLSI) silicon integrated circuits and III-IV semiconductor heterojunction and quantum well devices requires the capability to measure and control the across-wafer temperature to $\pm$ 1° C at temperatures ranging from 150° C to 1100° C depending on the type of fabrication processes used. Currently either thermocouples or optical pyrometers are used for measuring the wafer temperature. Thermocouples in contact with the wafer provide the actual temperature of the wafer only in the region of the contact point. While fairly reliable, thermocouples suffer from slow response time, and their lifetime is inversely proportional to the process temperature. Optical pyrometers, on the other hand, respond rapidly, but the measured temperature can be unduly influenced by variations in the wafer emissivity which is a function of the number and type of layers on the wafer. In addition, the reliability of pyrometers is of concern. For the most part, these techniques are also restricted to measuring the temperature at a point or small region of the wafer. The objective of this project is to develop an economical thermal sensor capable of measuring in-situ the temperature distribution in semiconductor wafers.

## Approach

The approach is as follows:

Task 1 - Refine functional requirements.

Task 2 - Acquire specimens and test instrumentation.

Task 3 - Assemble test apparatus.

Task 4 - Take temperature measurements.

Task 5 - Characterize and analyze temperature resolution and sensor performance.

Task 6 - Develop design drawings of proposed Phase II prototype.

## Benefits

An accurate and reliable in-situ whole-wafer temperature measurement technique will have an immediate commercial market in temperature monitoring and control for a wide variety of thermal processing technologies such as rapid thermal processing, molecular beam epitaxy and metallo-organic chemical vapor deposition.

## Status

*Active*
*Start date: April 1997*
*End date: December 1997*

## Resources

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# Zero Dump Electroplating Process Development

**Contract Number: F33615-95-C-5506 ALOG Number: 1342**

## Statement of Need

Metal finishing and printed circuit board (PCB) plating facilities directly or indirectly perform electroplating for the Department of Defense. Almost all of these companies have installed waste water treatment systems to comply with the Clean Water Act. These companies generate toxic metal waste streams.

Plating and rinse water baths are dumped because of the accumulation of contaminants which limits their usefulness. Although large volumes of waste water result from dumping rinse water baths, greater than 90 percent of the metal waste discharge is a result of dumping the plating bath. A major source of the contamination in the plating bath is the presence of additives that are used for deposit property control. The objective of this project was to develop and demonstrate an electroplating process that can achieve high quality coatings and precise property control without the need for additives in the plating baths. High quality coatings and zero additives implies zero dumping. This precise property control is achieved by using a periodic current (PC) plating process to obtain uniform electrocoatings. Applications of this technique to the printed circuit board manufacturing and metal finishing industries eliminates the need for additives in their electroplating activities for both the Department of Defense and commercial applications.

## Approach

The program included:

1) Development of a database and software module to relate coating properties to pulsed plating parameters,

2) A pilot scale engineering evaluation of the additive-free plating process, and

3) A commercial demonstration in the production facilities at the Raytheon Equipment Division Manufacturing Interconnection Facility. Technology transfer to the defense industrial base will be aided by a demonstration at the National Defense Center for Environmental Excellence.

## Benefits

The successful application of PC electroplating process technology in electronics manufacturing has a number of environmental benefits. First, removing the dependence on organic additives for process and deposit property control increases the usable life (number of turnovers) of the bath. Second, the process eliminates copper etchback in through-hole metallization. Use of a reverse current pulse replaces the etchback step and alleviates a large bottleneck in the PCB manufacturing process. This translates into significant increases in throughput for the plating line which ultimately results in less energy consumption and less waste.

## Status

*Active*
*Start date: February 1995*
*End date: December 1997*

## Resources

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# Activity-Based Costing for Agile Manufacturing Control

**Contract Number: F33615-95-C-5516 ALOG Number: 1361**

## Statement of Need

In a traditional cost accounting system, overhead costs are accumulated into overhead accounts and then allocated to products based on the amount of direct labor each product requires. This system worked well when direct labor was a large part of costs, but firms that make the significant investment in agile technologies often find themselves less profitable and their market reduced if they don't understand the impact of these new technologies on their cost structure. Activity-based costing offers a solution to this problem by assigning job costs based on the actual use of firm resources. However, this is often seen as only a "big" company solution. Very few small companies have implemented activity based costing in conjunction with a shift toward agile manufacturing. This project's objective was to determine and quantify the costs and benefits of using activity-based costing in a small company environment to support an agile manufacturing strategy.

## Approach

This effort was conducted in five steps.

• Step 1 - The contractor identified six small- to medium-sized companies which were committed to serve as study and implementation sites. These companies were equally split between plastic parts processors and machining firms. Quantitative metrics were developed to measure the current performance (as-is model) of each of the six implementation sites.

• Step 2 - The contractor then constructed a conceptual outline of each of the company's cost-flow patterns within an activity-based costing structure. This served as a blueprint for developing a day-to-day cost accounting system that was activity-based and accurately reflected the costs of the products and process of the business unit.

• Step 3 - A computer-based cost accumulation model of the company that simulates the activity-based cost flows was developed. This model provided accurate and relevant product costing rates and served as a tool for calculating the incremental costs that resulted from potential courses of action.

• Step 4 - The "as-is" and "to-be" differences were analyzed to determine significant improvements, significant cost increases, and any other significant changes that could be used to determine the effectiveness of activity-based costing in gathering accurate job costs.

• Step 5 - A small company activity-based costing implementation guidebook and a one-day workshop to present and explain the implementation process to interested companies were prepared. The guidebook and workshop were focused on the firms participating in the Agile Manufacturing Pilot projects. Broader dissemination will take place through the NIST Manufacturing Extension Partnership.

## Benefits

This effort allowed:

• Faster conversion of small companies to ABC implementation.

• Small companies to successfully bid on a wide range of commercial and military products.

• Strengthening of small business infrastructure.

## Status

*Active*
*Start date: January 1995*
*End date: March 1998*

## Resources

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# Advanced Collaborative Open Resource Network

**Contract Number: F33615-94-C-4450 ALOG Number: 1381**

## Statement of Need

In early 1995, a solicitation was held to add service providers to the ACORN project. Among the broad spectrum of responses received, a coherent focus was developed among the top scoring proposals in the field of mechanical design and manufacturing. This includes two high-level network-based components:

1. Identification, location and acquisition of catalog parts.
2. Design, rapid prototyping and acquisition of cast and/or machined parts.

In addition, this aspect of the program seeks to provide three essential elements:

1. Access to the technology by a wide range of organizations including small business.
2. Tools to facilitate search, acquisition, design and prototyping.
3. Education and professional training to assure that the skills needed to utilize ACORN technology are available to all.

The objective of this effort was to provide network based engineering and design software tools which can be utilized on the emerging national information infrastructure.

## Approach

ACORN built upon work emerging from Agile Manufacturing Information Infrastructure efforts such as EINet, which were aimed at exploiting Internet technologies for multimedia documents, wide-area information services, information agents, and electronic commerce. ACORN extended those technologies to facilitate engineering and manufacturing on the Internet, and included the use of design and manufacturing services, on-line searches of design libraries and part catalogs, distributed team collaboration, and acquisition of parts and services.

## Benefits

The software tools developed will enable critical design knowledge capture, design re-use, local/remote engineering collaboration and provide interfaces to rapid prototyping services. Existing and evolving engineering and design software tools were selected from both industry and university resources. The selected software tools will provide the capability to design new products using traditional methods such as numerical control programming, as well as new state-of-the-art manufacturing capabilities. ACORN provides assistance and enabling technologies to establish these collaborative tools on a nationally available information infrastructure.

## Status

*Complete*
*Start date: April 1994*
*End date: July 1997*

## Resources

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*DARPA Funded*

*Contractor:*
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*JDMTP Subpanel:*
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# Advanced Tools for Manufacturing Automation and Design Engineering

**Contract Number: F33615-94-C-4427 ALOG Number: 1246**

## Statement of Need

Development of electro/mechanical/optical systems generally requires a high degree of integration of advanced technology components. The high degree of accurate and timely communication required between design disciplines extends today's development cycle time. Electro/mechanical/optical system design is performed by a multi-disciplinary team of people, each executing a part of the design. The team is directed by systems engineers who integrate design analyses into total design and communicate trade-offs among the team members. Designers predict failure mechanisms and perform reliability assessments by examining the final design. Reliability problems that arise force costly redesign late in the cycle. This iterative process is prone to human error and is time inefficient. The objective of this effort was to develop and demonstrate a design advisor to link a statistical modeling and an analysis tool capable of optimizing E/M/O system designs for high manufacturing yield. This was accomplished by extending existing Design of Experiments software and integrating these in a standard computer-aided design framework.

## Approach

This program developed an Infrared (IR) System Design Advisor (IDA) to automate infrared sensor system design, automate integration of design analyses and trade studies, perform parametric analyses of the design components, and select desired parameters that meet IR sensor design requirements. It linked tools for mechanical, electrical, optical, performance, statistical, reliability and requirements design and analysis.

The tool interfaced was a design-of-experiments statistical modeling and analysis tool capable of optimizing electro/mechanical/optical system design for high manufacturing yield. The IDA tool was integrated with design-of-experiments and is capable of accepting and using output information from these tools as well as that from computer-aided engineering tools to address trade-off and heuristic optimization of electro/mechanical/optical systems. The tools are encapsulated in a CAD Framework Initiative (CFI) compatible framework environment.

## Benefits

Product development cycle time is lessened through the reduction of design cycle time and an ensured first-pass success.

### Status

*Complete*
*Start date: October 1994*
*End date: October 1996*

### Resources

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# Agile Manufacturing Information Infrastructure

**Contract Number: F33615-94-C-4400 ALOG Number: 218**

## Statement of Need

People have been building infrastructure to support their applications for as long as they have been writing programs. The goal of any infrastructure is to provide some leverage for making applications easy to build, extend, upgrade, and generally maintain. As the world becomes increasingly large and more heterogeneous, people have built many different programs using many different (but usually homogeneous) infrastructures. Large and complex distributed systems have survived by building ever higher layers of infrastructure. Relatively recently, people have been building infrastructures that attempt to deal with a more heterogeneous world (e.g., for databases, or in some cases, operating systems). Unfortunately, the tower of babel of different infrastructures reached the point of imminent collapse. Something other than another layer of meta-infrastructure was needed to stop spiraling costs and give users confidence that the plethora of interesting applications that have been developed and will continue to be developed can somehow have a chance of working together. What was needed was an infrastructure that can itself change and adapt and grow, not just in the number of agents or services, but in the details of the internal protocols as well. Agile Manufacturing Information Infrastructure (AMII) provides the requisite network tools and utilities to support manufacturing enterprises. This allows manufacturers to dynamically respond to market opportunities and compete more effectively.

## Approach

The focus of AMII was on the following four areas: 1) established core set of infrastructure services by defining initial candidates for network and application tools, developing an architecture specification for access to core services, and by integrating and deploying a base set of services to support selected pilots; 2) identified additional services for development by specifying and developing needed applications for pilot scenarios, and creating on-line engineering and catalog services to pilots; 3) selected pilots of varying scope for demonstration through the identification of scenarios employing applications and methodologies of low, medium and high degrees of complexity, deploying scenario applications over the AMII, and providing access to and support in use of AMII environment by users of scenario; 4) tracked technology transfer and benefits by the dissemination of information using AMII, created commercialization strategy for AMII services and applications, and identified metrics for measurement benefit and added-value.

## Benefits

The Agile Manufacturing Information Infrastructure program enables research prototyping and commercial deployment of manufacturing technologies.

## Status

*Complete*
*Start date: December 1993*
*End date: March 1997*

## Resources

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*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Agile Manufacturing: Virtual Enterprise Engineering Environment

**Contract Number: F33615-96-C-5601 ALOG Number: 1474**

## Statement of Need

An enterprise is a system whose framework is defined by a collection of processes and information. Because of the required rate of change and today's market demand for high quality, agility often requires collaboration of multiple enterprises, each contributing their core competencies to a "virtual enterprise" (VE). A VE is itself an enterprise system. Thus, the VE will have its own processes and information systems that must be rapidly defined, designed, constructed, and implemented. The VE processes and information systems must integrate seamlessly with those of the member organizations. This integration extends from such simple processes as time and attendance recording, to more complex processes such a material ordering and receiving, to still more complex processes such as an integration product and process development (IPPD). Further complicating the situation is the fact that an individual enterprise will likely participate in multiple VEs at the same time. The VE team is faced with the challenges of enterprise design within a distributed environment involving diverse corporate cultures. Differing levels of product, process, and information infrastructure maturity across the members on the VE team further complicate the situation. Addressing this situation effectively requires an innovative adaptation and integration of methods, tools, and environments that have been developed for more traditional reengineering in more homogeneous settings.

The objective of this effort is to develop an integrated environment for the analysis, design and construction of virtual enterprise for the realization of a specific goal, such as developing a weapon system or manufacturing a product.

## Approach

The approach will be to use state-of-the-art business analysis tools and business reengineering tools, in addition to process and knowledge interchange methods to build a virtual enterprise engineering environment.

## Benefits

This program will provide the languages, software tools, and knowledge bases to enable correct first time designs of agile manufacturing enterprises that have predictable performance and are rapidly realizable.

## Status

*Complete*
*Start date: December 1995*
*End date: June 1997*

## Resources

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*DARPA Funded*

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# Agile Web

**Cooperative Agreement Number: F33615-94-2-4412 ALOG Number: 1211**

## Statement of Need

It is clear that we were entering the next century in the midst of an ever-changing global economy. End users have increased their demands not only for higher quality, but for products specifically designed and produced to meet their personal needs. This has meant a shift from Henry Ford's mass-production paradigm with product runs of one instead of thousands. Furthermore, the life cycle of even mass-produced products has declined rapidly, necessitating almost constant production changes. Complex high-tech parts are now capable of being produced almost anywhere in the world with state-of-the-art processes. Companies no longer have the time and resources to manage large numbers of suppliers, and they are looking for fewer suppliers who can take on more responsibility. Faced with both increasing customer demands and global competition, these small companies need an advantage, some differentiation, to retain and grow their business and to help their customers succeed.

## Approach

The program explored ways in which a regional collection of 18 small- to mid-sized manufacturers could collaborate using innovative and agile business practices to address new and expanded markets. By easily pulling together the competencies needed to address a market opportunity, a temporary or virtual collection of companies can collaborate rapidly to respond to a limited, but potentially lucrative, window of opportunity. By partnering to obtain access to preexisting competencies rather than developing them, time-to-market can be dramatically reduced and a company's range of projects can be greatly increased. The project showed that developing trust and solid relationships among the participants, led to an enhanced competitive position for the suppliers and optimal, value-added solutions for the customers. In addition, the experiment showed that the key to developing an effective web of suppliers is to foster solid relationships, identify core competencies and to work with customers as partners to provide optimal solutions. The experiment resulted in a unique for-profit corporate entity made up of the 18 initial companies that will continue providing integrated, optimal solutions through a supply chain that has unprecedented flexibility in all facets of manufacturing and design engineering.

## Benefits

- Provided a documented experiment in the formation of a Virtual Company
- Improved IPPD using actual and timely manufacturer process capability knowledge
- Created a reconfigurable organization capable of meeting demanding DoD requirements
- Provided a broad array of expertise and solutions

## Status

*Complete*
*Start date: January 1994*
*End date: January 1997*

## Resources

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# Behavior Analog Fault Simulation

**Grant Number: F33615-96-1-5603 ALOG Number: 1422**

## Statement of Need

Analog and mixed signal testing follows different test methodologies from digital testing and is a bottleneck that not only leads to high testing costs, but also causes significant 'time-to-market' delays. Testing of mixed signal modules is also exacerbated by the high chip density and small interconnect line dimensions of new multichip modules (MCM). Many of the conventional approaches to testing used for printed circuit boards are not applicable to dense MCM testing, for example bed-of-nails testing techniques.

The objective is to develop methodology algorithms and prototype tools for performing behavioral analog fault simulations.

## Approach

The focus of this program is to use behavioral modeling for both good circuits and faulty circuits, based on a mixed signal hardware description language, VHDL-A. By exploiting the understanding gained recently in such areas as experimental design, control theory, system identification and applying the latest optimization techniques developed in mathematical optimization, new test algorithms can be developed. Hard-to-detect faults will be identified early in the design phase, which will facilitate design-for-test. New methods will be demonstrated through computer-aided design (CAD) and simulation software tool development.

## Benefits

This program will develop a new design methodology that will cut both cost and time spent on mixed signal testing. The goal is to provide more automated test generation during the design phase which will integrate analog and digital testing. The key to this goal is to use fault-driven testing for both analog and digital testing. By isolating difficult to test faults, design-for-test can be used more effectively. This technique also applies to advanced fault detection and fault isolation which maintains mixed signal module manufacturing processes.

Project Anoracle is currently developing a comprehensive methodology and a set of software tools to address the design and test challenges of mixed-signal circuits and systems, based on the upcoming IEEE VHDL-AMS (VHSIC Hardware Description Language - Analog Mixed-Signal) standard. Several key technologies have been developed to date, including behavioral model optimization, canonical symbolic analysis, fault simulation and test generation under process variations, rapid fault isolation, and distributed mixed-signal simulation. All these techniques have improved the state-of-the-art significantly, and have been presented at several major electronic design automation conferences, including ICCAD '97, DAC '97, VLSI '97, VTS '97, ASP-DAC '97, and EuroDAC '96. An overall of 10 research papers have been published. A joint project has been initiated by Rockwell Semiconductor Systems to adopt Project Anoracle's technologies. For one design, using optimization techniques reduces power consumption by over 30 percent. Project Anoracle's research will enable the VHDL-AMS simulation and model based design and test methodology. See the Project Anoracle Homepage: www.eng.uiowa.edu/~anoracle/

## Status

*Active*
*Start date: December 1995*
*End date: February 1999*

## Resources

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# Below-A-Minute Burn-In for Known Good Die

**Contract Number: F33615-94-C-4432 ALOG Number: 1270**

## Statement of Need

The challenges of assembling low defect level electronic subsystems at low cost were driving the computer and workstation business to look for techniques for improving part quality while reducing screening costs. Printed circuit assemblies were often found to be defective despite the fact that vendor parts were within specification upon delivery.

The program objectives were to develop, evaluate, and make available technologies for delivering known good die. The program developed and demonstrated the technology available today for achieving cost-effective known good die with reliability and quality as good as, or better than achieved for equivalent single-chip package parts.

## Approach

This program had four major technical task areas as follows:

Task Area 1 - Bare Die BAMBI Prototype System Development: The objective of this task was to specify, develop, and integrate a prototype bare die BAMBI test system within twelve months after program start. Using a concurrent engineering approach, a team of engineers assembled within the first month of the program from each of the associated companies to develop a prototype system specification.

Task 2 - Bare Die BAMBI Protocol Design Phase: In parallel with the prototype system development, Insyte and Hewlett-Packard (HP) reviewed BAMBI as currently implemented on single-chip packaged parts, and the supporting data and test methods to develop a test protocol, with appropriate statistical accept/reject criteria for use with bare die to develop a Known Good Die Test Method. This analysis included evaluation of stress gradients currently used and guidelines for developing statistical signatures for use in the BAMBI process. Experimentation was also performed where necessary by Insyte to support the correlation between BAMBI technology and basic physics of failure mechanisms.

Task 3 - Bare Die BAMBI Known Good Die Validation: Validation of the BAMBI technology in screening bare die for quality and reliability was executed during a twelve-month effort following the installation of the bare die BAMBI prototype system at Insyte. A minimum of four different part types including DRAMs, SRAMs, microprocessors, and digital signal processors were obtained from integrated circuit manufacturers, across a number of manufacturing lots, using their current standard bare die manufacturing flow.

Task 4 - Bare Die BAMBI Information Products: With the advent of a breakthrough technology such as BAMBI, the need for information products became paramount for rapid general acceptance of the technology. As part of the management and technical support function of this program, Insyte worked with HP toward the development of an information and knowledge base which was used to describe the theoretical constructs on what BAMBI is, why BAMBI works, how BAMBI works, and how to implement BAMBI on a fabrication line or MCM assembly process. This includes publication of the associated research and history of BAMBI for the first time in research and technical journals, as well as development of information products which will facilitate rapid acceptance of this technology.

## Benefits

The revolutionary BAMBI technology, developed and used exclusively in single-chip package applications, was extended to bare die screening and brought to the commercial marketplace to support MCM technology infrastructure.

## Status

*Complete*
*Start date: June 1994*
*End date: March 1997*

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# Built-In Test of Known Good Die

**Grant Number: F33615-96-1-5610 ALOG Number: 1423**

## Statement of Need

Analog and mixed signal testing follows different test methodologies from digital testing and is a bottleneck that not only leads to high testing costs, but also causes significant 'time-to-market' delays. Testing of mixed signal modules is also exacerbated by the high chip density and small interconnect line dimensions of new multi-chip modules (MCM). Many of the conventional approaches to testing used for printed circuit boards are not applicable to dense MCM testing, for example bed-of-nails testing techniques.

The objective is to develop methodology algorithms and prototype tools for performing behavioral analog fault simulations.

## Approach

This project will research and develop tools and methodologies for the automation of test pattern generation for mixed signal modules. The project will also research tools and methodologies to determine stuck and delay faults for circuits as a part of known good die development.

The Delay Fault Partial-Scan Sequential Circuit Built-In Self-Testing (BIST) will try to develop a nearly automatic way to insert stuck- and delay-fault BIST hardware into a digital military chip with no delay overhead, fast computation times, and five percent chip area hardware overhead. Delay-fault partial-scan sequential BIST allows reliable delay testing of digital defense chips that operate at frequencies >= one Gigahertz, with low chip area overhead. Anyone designing highly-reliable circuits for radar, communication and encryption/decryption should be interested.

The Markov-process Sequential Circuit Automatic Test Pattern Generation (ATPG) will try to characterize huge state machines as a Markov process using little memory, but eliminating most test generation backups.

The Path Delay Fault Sequential Circuit ATPG will develop a path delay fault Sequential ATPG tool to generate test patterns for both stuck- and path delay-fault testing.

The Mixed-Signal Analog/Digital Circuit ATPG effort will develop a theory and tool that allow ATPG of analog test waveforms for mixed analog/digital chips with properties that: generate waveforms which assist in testing digital and analog parts; select correct frequencies to test for harmonic distortion; and eliminate many analog simulations in the test generation process that are presently needed to generate test waveforms by hand. This method generates the first accurate analog circuit fault models based on the designer's output analog circuit waveform phase and magnitude tolerances. Mixed-signal ATPG is needed for mixed-signal circuits for fire control, guidance, and wireless communication to reduce the cost and trouble of creating analog test waveforms for hardware.

Analog Circuit Fault Simulation will develop a theory that allows modeling of many noise sources in validating whether a given analog waveform will be useful for analog testing of mixed-signal ckts. Analog circuit fault simulation is useful for mixed-signal military circuits where analog and digital parts reside on one chip. The tool will model environmental and tester noise, and indicate whether noise will invalidate the testing waveforms.

## Benefits

This project will provide the tools necessary to provide analog and mixed signal known good die to the industry.

## Status

*Active*
*Start date: February 1996*
*End date: March 1999*

## Resources

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# Collaborative Optimization Environment

**Contract Number F33615-96-5613 ALOG Number 1483**

## Statement of Need:

Today, the need for optimization in integrated product and process development (IPPD) is rapidly becoming understood, but the penetration of this technology, particularly for realistic problems, is low. The main reasons for this are that the tools and infrastructure required to support optimization-based IPPD have been slow in their evolution, and the investment required by individual companies to develop and integrate the requisite technologies within their own organizations is too costly, and has an associated high risk. In addition, the optimization technology required to support such a vision has only emerged within the last few years.

## Approach:

Under the Rapid Design Exploration Optimization (RaDEO) program, the General Electric Research and Development Center/ Engineous Software team proposes to develop a unique Collaborative Optimization Environment (COE) software platform, which will provide a key missing technology for developing affordable products with optimum performance through the systematic application of optimization to the IPPD process. Specifically, the COE will address collaborative optimization along four fronts, including:

- collaboration among optimization algorithms
- collaboration among multiple disciplines (MDO)
- collaboration among multi-level decomposed systems (MLO)
- collaboration among organizations

## Benefits:

The COE kernel along with its design automation, integration, and optimization utilities, will offer a seamless development environment necessary for engineers to model, analyze, and optimize complex products and processes. It will be an order of magnitude faster and more efficient than currently available methods. Specifically, the system will contribute to improving product quality, reducing design cycle time, and reducing application development effort. These benefits will be demonstrated via two real world applications in the project: an aircraft performance optimization problem and a detailed disk design problem.

## Status

*Active*
*Start Date: May 1996*
*End Date: May 1999*

## Resources

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# Collaborative University/Industry Manufacturing Research

**Grant Number: numerous  ALOG Number: 1263, 1411-1414**

## Statement of Need

The objective of this joint National Science Foundation/Manufacturing Technology funded effort is to stimulate and expand research of Manufacturing Technology using collaborative research among university and industry to create and accelerate the insertion of new technologies into the Department of Defense, aerospace manufacturing and the supporting industrial base.

## Approach

This program is strategically focusing university basic research on DoD manufacturing and engineering requirements. The Collaborative University/Industry Manufacturing Research program is an overarching concept intended to build strong academia and industry relationships for development of needed manufacturing technologies. Each individual project is submitted against topics by the university and its industrial partner(s), who collaborate and perform technical work, publish technical papers and develop new text books with real industrial case examples. The industrial partners and the university will exchange personnel ensuring the technology researched is mature as milestones are passed during the life cycle of development.

Projects producing "Technology Nuggets" are prioritized and "Pathfinder" development projects are selected and funded. The process renews annually when MT and NSF create an announcement containing manufacturing topical areas of interest such as: Affordability Technologies; Rapid Design; and Generative Process Planning. NSF publishes the announcement for potential grants to universities with organized research programs; hundreds respond and many are relevant to MT requirements. MT selects the highest ranked prioritized relevant proposals, from the NSF Peer Review results, and funds or co-funds with NSF.

## Benefits

The program is intended to capitalize on NSF and Air Force Manufacturing Technology strengths across the life cycle, stimulating education processes and improving technology transfer in key market sectors.

## Contractor

The following grants have been awarded to universities as part of the joint MT/NSF program:

**Robust Scheduling and Diagnostics Using Simulation-Based Optimization**
(97-1) Georgia Tech will conduct research focusing on scheduling in a real world environment so as to minimize cost. It makes none of the usual idealized assumptions, rather it assumes finite capacities and stochastically affected, variable lead times. The research plan is limited to printed circuit board manufacturing. MT should seek to broaden the work to include engine or airframe manufacturing systems.

**Optimal Pre-Stressing Surfaces by Superfinish Hard Turning for Maximum Fatigue Life**
(97-2) Purdue University will show that under certain conditions of feed, speed and tool condition, compressive stresses are created in the workpiece. This sets the stage for increased fatigue life as well as eliminating the need for grinding and other surface finish operations. MT is currently supporting this work, which has led to a proposed expansion. MT should seek to get the work extended to include titanium and aluminum-lithium alloys.

## Status

***Active***
***Start date: September 1995***
***End date: September 1998***

## Resources

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# Collaborative University/Industry Manufacturing Research

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**Enterprise Design: Integrating Product, Process and Organization**

(96-1) Georgia Tech will look at the structure of the internal enterprise, focusing on resources, people and business processes viewed through the prism of product design, simulation and optimization. The external structure will be on the light of supply chain dynamics. Texas Instruments will serve as the "lab."

**The Effect of Pre-Existing Residual Stress in Dry Superfinish Hard Turning**

(96-2) Purdue University will examine dry hard turning, which offers the prospect for a substantial reduction in processes and lowering of cost. Residual stresses must be understood and modeled. This will lead to techniques for machine tool error compensation for one-step superfinish turning.

**A Distributed Decision Framework Integrating Manufacturing Planning and Supply Chain Management**

(96-3) Lehigh and University of Pennsylvania will create a distributed decision structure which eliminates top-down centralized control and enhances flexibility in dealing with multiple product supply chains. Working with Ford and Lucent, researchers will seek ways to better utilize capital intensive manufacturing equipment.

**Supply Chain Management for Electronics Manufacturing with Product Recovery and Remanufacturing**

(96-4) Purdue University will use chain models to support production, purchasing, disassembly and remanufacturing activities over the short term and enhanced planning over the long term. Minimum cost trade-offs for recycling/remanufacturing judgments will be sought.

**Rapid Design and Analysis of Advanced Manufacturing Systems**

(96-5) University of Florida will develop a new analytic model of material handling devices and flexible manufacturing systems will also include factors describing component reliability and maintainability. Then the interactions among components will be approximated so as to enhance rapid investigation and design. Caterpillar at Peoria will serve as the "lab."

**Optimal Design of Bulk Forming Processes**

(96-6) Rensselaer Polytechnic Institute will focus on bulk forming processes such as rolling, extrusion, and forging. Finite element models will be developed for the deformation thermo-viscoplastic-contact problems. Results will be experimentally tested.

**A Responsive Process Planning System in Agile Manufacturing**

(96-7) University of Missouri will examine present process planning systems, which are rule-based. They have low knowledge content and a hard-to-change structure. Case studies will provide information formatted for machine learning. The new system will be more responsive and will take advantage of prior experience.

**A Methodology for Promoting the Design & Justification of Innovative Solutions to Flexible Manufacturing Problems in Traditional Factories**

(95-1) New Jersey Institute of Technology will develop a process to manage the design, justification and implementation of affordable technological

# Collaborative University/Industry Manufacturing Research

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solutions which will enable flexible manufacturing. In designing FM solutions consideration needs to be given to the type of flexibility needed, workforce training and adaptation to change and financial investment matters. MT is interested because of the impact on commingled production in small manufacturing enterprises. Industrial partners include Universal Valve Co., Automatic Switch Co., and Gross Associates.

### Life Cycle Costs of Manufacturing Activities and Technological Innovation

(95-2) Texas A&M University will develop cost models for both civil and defense manufacturers which are useful in assessing the cost impact of technological innovation and design changes on the product life cycle. Fundamental to the proposed cost modeling approach is the premise that a standard set of topological models for cost-drivers can be derived and implemented. These models will access a set of relational data base files which contain time, cost and resource requirements. Three industrial partners will participate: Westinghouse, Rockwell International, and Tinker AFB.

### Flexible Accounting Systems in Dynamic Manufacturing Environments

(95-3) Iowa State University will develop a flexible accounting system that integrates four alternative costing methodologies within the product life cycle framework. The research will link product and process technology with a dynamic cost accounting system that incorporates: target costing (product design); Kaizen costing (product introduction); standard costing (product maturity); and life cycle costing (product elimination/redesign). The accounting system will permit managers to more realistically evaluate the potential of technological innovations.

### Innovation, Implementation, and Costs

(95-4) Tennessee Technological University will develop a concurrent design/cost tool for management to use in the deployment of new technology. Both specific and general information will be accumulated for the development of methodologies for uncovering and estimating hidden costs of technological implementation. A framework will be developed which captures how the interrelationship between design, operational management, marketing, engineering, and employee involvement, impact costs. A groupware information system will be developed and will provide all constituents dynamic cost information to better make design/product cost trade-offs. The framework will then be implemented on a broadbase network such as the worldwide web, to promote concurrent design and costing.

### Decision Making with Incomplete Information in an IPPD Enterprise - A Management Decision Tool for Cost Modelling and Affordability Applications

(95-5) Florida A&M and Florida State University will develop a tool for engineering managers to estimate the impact of new technologies on manufacturing and life-cycle costs, and to incorporate the estimates concurrently into engineering design with the presence of uncertainty in the estimates. This will be based on the analysis of existing technical, human, and organizational subsystems of the total production system as well as on the feasibility of modifications, innovations, and new technologies.

# Context Integrated Design

**Contract Number: F33615-96-C-5614 ALOG Number: 1446**

## Statement of Need

Design of complex products, with critical performance, reliability, and cost requirements, is a team effort. Teams invent, design, analyze, refine, simulate, build, test, and document the product. To perform these tasks well, they must create, distribute, interpret, and assimilate nearly overwhelming amounts of information. Designers work in a relay-team environment, in which they must transfer information through space and time, and rapid exchange and assimilation of information is essential for success.

Context Integrated Design (CID) consists of a set of software agents which work through a hypermedia shared project notebook to organize, interpret, and coordinate information in the context of the task at hand. To provide this information, the software agents must use product/process models. The development of such a model adequate for in-depth reasoning can easily consume more resources than the design of the product itself. This makes the general concept infeasible, except for products that are repeatedly redesigned. CID overcomes this problem by taking the innovative approach of providing a set of agents, each handling a modest information manipulation task. Since each agent handles a specific limited task, it needs only a specific and often rudimentary mode of some critical aspect of the product. CID uses a semiformal model embedded in an informal shared hypermedia notebook, where "semiformal" means there is enough structure in the entry so that it is machine interpretable for certain purposes, while requiring minimal effort for construction and modification.

## Approach

The contractor will:

• Develop a distributed routing mechanism consisting of an appropriate routing protocol and a CORBA compliant application programmer's interface (API).

• Specify and develop dependency, coordination, behavior, and design rationale models, model templates, and model editors.

• Identify relevant design process information and information flows, and identify and implement corresponding software information agents.

• Demonstrate the CID periodically throughout development.

• Transition CID technologies to other MADE contractors.

The initial release of the CID Design Environment (Version 0) is complete and being validated by supporting conceptual and preliminary design activities for the Lockheed AIT Missile Seeker. Planning has begun to demonstrate CID in an additional test bed in conjunction with General Electric, Rocketdyne, and Stanford University, to support the design of a rocket propulsion system.

## Benefits

This program will provide mechanisms for information search, retrieval and filtering, as well as capturing design history. CID will realize participatory design methodologies through extension of the concepts of the electronic engineering notebook and agent-based engineering collaboration. The CID environment will enhance information discovery, evaluation and incorporation in a geographically distributed design environment.

## Status

*Active*
*Start date: March 1996*
*End date: February 1998*

## Resources

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# Continuous Electronics Enhancements using Simulatable Specifications

**Contract Number: F33615-93-C-4304 ALOG Number: 220**

## Statement of Need

Currently, fielded systems are delivered with obsolete, or nearly obsolete, electronic technologies. One reason for this phenomenon is that of all the technologies comprising a defense system, the electronics technology undergoes the most rapid change during the course of a system development. An additional problem associated with electronics subsystem development is the presence of integration errors due to human misinterpretation of written specifications. Today integration error rates due to written specification misinterpretation can exceed 60 percent for the integration of microcircuits and multichip modules at the printed circuit assembly (PCA) level of integration.

The CEENSS program will provide the capability for vendor independent descriptions and designs of electronics products. In so doing, it will increase the line replaceable module (LRM) design initial verification and manufacturing success rate to 95 percent and also reduce the development time of electronic systems by 75 percent. This will be accomplished through the establishment of methodologies and guidelines for defining, describing, developing, implementing and using simulateable specifications (Sim Specs) via VHSIC hardware description language (VHDL).

## Approach

The program will develop and demonstrate methodologies and guidelines for Sim Specs and provide a complete electronic product description of LRMs with Sim Specs. The approach further provides for a Sim Spec toolkit through the update of commercial electronic design automation (EDA) tools and their environment which allows for the incorporation of VHDL extensions to support the Sim Spec methodologies. The approach also leverages ongoing commercial and governmental related electronics programs to provide for the design reuse and prototyping-plus concepts.

## Benefits

This effort will increase first pass success for the manufacture of LRMs to 95 percent, decrease the presence of obsolete electronics resident in newly delivered systems, and increase reuse of past designs in development of new systems. To date, the CEENSS technology has been employed to design the Pulse Interval Processor (PIP) which is a Communication Navigation Identification (CNI) module. The CEENSS approach to the PIP design has provided direct benefits to the Joint Strike Fighter (JSF) Integrated Sensor Subsystem (ISS) program by providing a viable design and an 18 percent reduction in the design cycle time.

## Status

*Active*
*Start date: September 1993*
*End date: January 1999*

## Resources

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# Create a Process Analysis Toolkit for Affordability (PATA) Supporting the R&D Process

**Contract Number: F33615-97-C-5141 ALOG Number: 1569**

## Statement of Need

One of the hurdles in applying Integrated Product and Process Development (IPPD) to new technology is quantifying the transition cost and risk impact of critical design or architecture decisions. Determining how risk can be quantified for new technologies, how to base design decisions on process capabilities that aren't fully defined, and how to achieve in software the results being realized in electronics manufacturing, are questions which need to be answered. The Process Analysis Toolkit for Affordability (PATA) is a two year development and commercialization project, intended to be used by the Air Force Science and Technology (S&T) community, including industry, academe, and government, to ensure that research and development projects have viable, usable and affordable results. This Phase II Small Business Innovation Research (SBIR) project will develop, validate, and successfully commercialize a high-quality process analysis toolkit that enables life cycle performance cost and schedule affordability analyses, both during the research and development phase of Air Force technology development and during subsequent technology transition to acquisition or support. This effort is specifically focused on addressing the need for a software toolkit to support the S&T IPPD initiative, which aims at achieving more affordable technology by changing S&T culture and business processes throughout the Air Force laboratory environment, by applying IPPD principles to defense research.

## Approach

The contractor will prepare a project master plan and schedule, business plan, and marketing plan to drive the project. The project will be web-based and will use a technical review board to remain abreast of industry requirements and developments. The PATA system and training developed will be beta tested by the Air Force Material Command/Advanced Technology Demonstration (ATD) projects. The PATA tools will be launched from the web site for testing and then commercialization.

## Benefits

This effort will produce an inexpensive, easy to use toolkit, rich in functionality. It's inexpensive because it takes advantage of the rapidly growing Internet infrastructure. Its unique browser technology and related standards make it convenient and easy to use. It supports a wide variety of activities, from on-line shopping (transaction management) to information retrieval, application sharing and collaborative design.

## Status

*New Start*
*Start date: September 1997*
*End date: September 1999*

## Resources

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*SBIR Funded*

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# Decision Support System for the Management of Agile Manufacturing

**Cooperative Agreement Number: F33615-95-2-5525 ALOG Number: 1406**

## Statement of Need

The objective of this project was to specify, develop, and demonstrate an integrated supply chain analysis tool. In addition, improvements will be made to the supply chain performance such as reducing supply chain inventories and costs, and increasing the delivery rate.

## Approach

This effort focused on designing a decision support system (DSS) that improves decision-making capabilities while fostering supply chain integration. This DSS can be used to integrate data from various sources, formulate problems, generate and evaluate options, and measure decision-making quality. The DSS is based on quantitative models using data provided by diverse sources of information. The system enhanced the quality of individual and group decisions and uses interactive technology and client-server architecture. It is customizable to the needs and capabilities of the user. A demonstration this technology was made for both defense and commercial supply chains.

## Benefits

This program: reduced cycle time; improved issue effectiveness/ fill rate; reduced pipeline inventories; increased the effective usage of resources; and reduced overall supply chain costs.

## Status

*Complete*
*Start date: April 1995*
*End date: August 1997*

## Resources

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# Definition of Generic Production Cost Model

**Contract Number: F33615-97-C-5127 ALOG Number: 1545**

## Statement of Need

The Manufacturing Technology Division aggressively pursues advances in manufacturing technology which have broad applicability to the affordability and performance of Air Force systems. The focus of this general topic is to allow opportunities for major breakthroughs in the following areas: Composites Processing & Fabrication, Electronics Processing & Fabrication, Metals Processing & Fabrication, Advanced Industrial Practices, and Manufacturing & Engineering systems. New processing techniques, variability reduction tools, affordability improvements, manufacturing simulation and modeling, are a few examples of the types of proposals that are desired. The emphasis is on innovation, the ability to achieve major advances, and defense/commercial applicability.

The primary objective of this Phase I Small Business Innovation Research (SBIR) project is to create the generic core of a computer-based production cost model (PCM) to support systems program offices in the attainment of several acquisition reform initiatives. The PCM supports the information requirement of costs as an independent variable (CAIV), including aggressive cost goals, trade-off analyses, and incentive measurements.

## Approach

This program will develop the structural and performance criteria for the PCM. Once that has been established, the criteria will then be used in completing the PCM's conceptual design.

## Benefits

Benefits will be in identifiable savings in software development and the quality of information made available for management decision making.

## Status

*Active*
*Start date: March 1997*
*End date: December 1997*

## Resources

*Project Engineer:*
*Wallace Patterson*
*AFRL/MLMS*
*(937) 656-9220*

*SBIR Funded*

*Contractor:*
*Wallace & Company*

*JDMTP Subpanel:*
*Manufacturing and*
*Engineering Systems*

# Development of Adaptive Modeling Language for Knowledge-Based Systems

**Contract Number: F33615-96-C-5606 ALOG Number: 1476**

## Statement of Need

The overall objective of the Rapid Design Exploration Optimization (RaDEO) program is to develop engineering tools and information integration capabilities that could be used to evaluate an order of magnitude more design alternatives than is possible today in an attempt to optimize several product characteristics, and quickly prototype complex products and processes.

## Approach

As part of the RaDEO program, the contractor will develop an application to the Adaptive Modeling Language (AML) for knowledge-based engineering with the ability for application to all Department of Defense and commercial electromechanical systems. AML will be applied to the specified multidisciplinary design of gimbal systems, capturing knowledge to streamline the gimbal design process but allowing a software structure that permits creativity while simultaneously capturing the knowledge of the creativity.

## Benefits

This effort will develop an adaptive modeling language for domain-specific, knowledge-based engineering in the electromechanical design process. The resulting integrated CAD tools and methods including process knowledge will reduce product development cycle, increase design reuse and capture design functionality. The end system will be supported by commercial CAD tools that will have the capability of being applied to DoD and commercial electromechanical systems.

## Status

*Active*
*Start date: March 1996*
*End date: August 1998*

## Resources

*Project Engineer:*
*Alan Winn*
*AFRL/MLMS*
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*DARPA Funded*

*Contractor:*
*Lockheed Martin Corporation*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# E-3 AWACS Synchronizer Remanufacture Using VHDL

**Contract Number: F33615-97-C-5140** **ALOG Number: 1552**

## Statement of Need

The objective is to demonstrate an improved process for the cost and time effective management of electronic component obsolescence. This proof of concept project will serve as a model for further implementations at other defense industry facilities.

## Approach

The approach will be to use the VHSIC hardware description language (VHDL) to capture the form, fit, function and interface (F3I) simulatable description of the entire AWACS' synchronizer subsystem. This simulation model will be used to synthesize and manufacture an F3I-equivalent synchronizer for the AWACS.

## Benefits

Current parts obsolescence management approaches are focused on part for part replacement efforts. This approach is bankrupt for electronics subsystems such as the AWACS Synchronizer. In this particular case the obsolescence is so widespread that it is not at all cost efficient to redesign each and every needed component on a component by component basis. It makes much greater practical and economic sense to perform a form, fit, function, and interface replacement at the subsystem level of integration. The benefits of this approach is that there will be a subsystem replacement for the synchronizer subsystem consisting of two boards for the entire 19 board subsystem with greatly enhanced reliability and availability. The new process utilized for this approach will also be available for promulgation throughout industry for similar obsolescence resolution in the future.

## Status

*New Start*
*Start date: August 1997*
*End date: November 1998*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*Northrop Grumman Corporation*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Electric Component Commerce

**Cooperative Agreement Number: F33615-96-2-5116 ALOG Number: 1553**

## Statement of Need

Electronic systems and subsystems represent about 40 percent of the defense acquisition budget and are the critical enabling technology that differentiates our weapon systems. As the Department of Defense (DoD) downsizes, it has become increasingly important to keep access to affordable, advanced electronics technology by leveraging the high volume, leading edge, merchant manufacturing infrastructure. Historically, unique DoD requirements and relatively small production volumes have been incongruent with the merchant community's focus on high volume commodity products. Digital Market seeks to alleviate those barriers by increasing the flexibility of the merchant ESM infrastructure and streamlining the process by which new products are designed, sourced, and transferred to manufacturing.

## Approach

To achieve this goal, Digital Market built an on-line marketplace (digital.market) for electronic components that connects engineering and procurement organizations directly to their preferred distributors to exchange information and transactions in real time. A buyer or engineer can upload a Bill of Materials (BOM) and forecast information directly into digital.market and quote and order components in real time from multiple distributors. This accelerates the process and lets high volume ESMs cost effectively procure material for low volume DoD manufacturing projects where manufacturing times are dominated by component procurement, prototype fabrication cycles, producability analysis, and production setup times. Additionally, the ESMs decrease their design-build-test cycle time and ramp faster from prototype to volume manufacturing.

## Benefits

The system has demonstrated a 38 percent reduction in the overall cost of acquiring and managing materials, faster and more accurate information sharing in the supply chain, greater ability to respond to changes in engineering content and demand schedules, and immediate access for small quantity purchases. As digital.market gains more acceptance in the contract manufacturing segment, these efficiencies will be exploited to reduce the cost of manufacturing a large portion of future DoD and commercial products.

More information is available at the digital market homepage: www.digitalmarket.com

## Status

*Active*
*Start date: October 1996*
*End date: December 1998*

## Resources

*Project Engineer:*
*Bill Russell*
*AFRL/MLMS*
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*DARPA Funded*

*Contractor:*
*Digital Market*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Electronic Component Information Exchange

**Cooperative Agreement Number: F33615-97-2-5121 ALOG Number: 1527**

## Statement of Need

Component suppliers world wide desire to reach the global marketplace, and customers of electronic components want easy access to supplier information. The rapid expansion of the Internet has offered a practical technology infrastructure to support rapid information distribution. Through use of the electronic information distribution, data can be revised and broadcast immediately, without the expensive, time-delayed characteristics of today's publishing practices. However, without a degree of standardization for the form and content of these electronic packets of component data, customers will be unable to compare value across multiple suppliers, and could be required to re-key data from the selected supplier to make component data available to computer-aided design (CAD) systems used for the product design. The objective is to provide an overall architecture and set of standards which support the flow of reusable electronic component information from its source to the user.

## Approach

The project will be implemented as an industry partnership under Silicon Integration Initiative (SI2) bylaws. It will be led and managed by SI2 staff in partnership with sponsoring industry partners. Members of this partnership will include companies within the Pinnacles Consortium, Aspect Development, and IHS. Development will be performed by technical workgroups staffed by the member companies and under the direction of a project technical advisory board (PTAB). The PTAB will be represented by each sponsoring company equally and will have responsibility of setting priorities and design decisions during the development phases to assure rapid closure. SI2 will provide the lead for the overall architecture of the system and two technical workgroups will be responsible for the PCIS and CIDS development.

## Benefits

The payoff will be a professionally documented architecture for a standards-based system supporting electronic commerce of electronic components, and a formally balloted (through SI2 membership) set of standards which support that architecture. Additionally, this project will provide a commercially available suite of tools that operate with these standards to provide the open electronic commerce system architecture. These tools will be developed to prove and initiate widespread adoption of the standards within industry and to encourage competitive offerings over time. Finally, a proof of the viability of the commerce system will be provided by a formally documented test run by a major government contractor with results that clearly identify quantitative comparison with currently used approaches.

More information is available at the Electronic Component Information eXchange homepage: www.si2.org/ecix

## Status

*Active*
*Start date: December 1996*
*End date: December 1998*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Silicon Integration Initiative*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Electronics CAD-CAM Exchange

**Contract Number: F33615-96-C-5118 ALOG Number: 1524**

## Statement of Need

It is estimated that the electronics industry spends well over $150 million a year to capture design data and transport the information into the CAM environment. ECCE is a Defense Advanced Research Projects Agency (DARPA) funded program. The ECCE program will develop and demonstrate an integrated solution to providing compatibility between Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM).

The goal of the ECCE program is to design a format for carrying CAM information (CAM-F) in a way that ensures a viable, sustainable method of CAD/CAM and CAM/CAM information transfer. ECCE will also demonstrate how the CAM information model can be populated with CAD data, enabling error-free transfer of data from CAD to CAM.

## Approach

The ECCE technical approach applies the formalisms of information modeling to CAM. ECCE will create an information model, from the "manufacturer's point of view," that documents CAM information requirements. The CAM information model will be mapped to the CAD information model, as represented by EDIF 4.0.0. With the concurrence of the EIA and the Institute for Interconnecting and Packaging Electronic Circuits (IPC), ECCE will initiate changes to Electronic Design Interchange Format (EDIF) to better support CAD-CAM exchange.

## Benefits

By conservative industry estimates the lack of accurate CAD information to manufacturing costs U.S. industry $150 million annually in reengineering and scrap costs. This project will greatly reduce this number if embraced by the users. The information model and format will be made a joint EIA and IPC standard.

More information is available at the ECCE homepage: www.inmet.com/ecce

## Status

*New Start*
*Start date: December 1996*
*End date: March 1999*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Intermetrics Inc.*

*JDMTP Subpanel:*
*Manufacturing and*
*Engineering Systems*

# Electronics Sector End-to-End Pathfinder

**Contract Number: F33615-94-C-4431 ALOG Number: 1253**

## Statement of Need

The challenge for U.S. electronics sector defense dependent industries and the thousands of subcontractors who support them, is not simply finding new civilian markets for their technologies. These enterprises, large and small, must invent a new marketplace: an electronic, virtual enterprise marketplace, wherein the traditional barriers of distance, time, and communication are erased. Defense and commercial capacities are developed in a new strategic balance to meet the flexible requirements of economic growth and national security.

## Approach

This effort focused on the network by providing bandwidths that support interactive image-based applications and real-time multimedia applications. To be effective and support multiple small- and medium-sized enterprises across a large metropolitan area, the Nationwide Electronics Industry Sector Pilot (NEISP) demonstrated how high bandwidth demand items such as graphics engineering, multimedia applications including motion video and the like, are supported. To make a significant impact on the agile manufacturing business paradigms that drive small- and medium-sized enterprises, the network supports image-based applications as opposed to the text-based networking commonly supported in wide-area-networks now.

## Benefits

This program established an electronic network in the electronics manufacturing sector to overcome the barriers of traditional commerce: time, distance, communication, quality, and market access.

## Status

*Complete*
*Start date: August 1994*
*End date: June 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Arizona State University*

*JDMTP Subpanel:*
*Manufacturing and*
*Engineering Systems*

# Fast and Flexible Communication of Engineering Information in the Aerospace Industry

**Contract Number: F33615-94-C-4429 ALOG Number: 1251**

## Statement of Need

This project aimed to improve key processes in the aircraft industry by following a bottom-up process. At the same time, it deepened understanding of the top-level concepts of agility. Aerospace components and assemblies are procured through a complex web of parts and tooling suppliers. Crucial information necessary for part fitup and product performance can be lost in this web, necessitating extensive problem-solving activities. Speed and flexibility can be improved by examining both the problem-solving processes and the underlying customer-supplier relations. This program was coordinated with a parallel one in the automotive industry (Contract Number: F33615-94-C-4428, Fast and Flexible Design and Manufacturing Systems for Automotive Components and Sheet Metal Parts) to provide cross-fertilization, leveraging of common research activities, and adoption of best practices from both industries.

## Approach

Fast and flexible business activities are characterized by: organizing for change, virtual partnerships, valuing knowledge and skills, and enriching the customer. This project deepened understanding of these characteristics by studying specific assemblies built for and obtained from other companies. The methods used were process mapping to identify crucial transactions between people and companies, linking transactions to clusters of specific engineering data called features, identifying transactions that do not add value, identifying and inserting missing transactions, and speeding up the processes by providing computer tools and database access that connect people and their transactions to engineering features.

Aerospace items are highly engineered, made in low volumes, and subject to government procurement rules and intense regulation. Items studied include commercial and military fuselage and engine inlet assemblies, empennage assemblies procured from foreign sources, and examples of both paper and computer-based design data. This variety gave the study generality. Conditions observed include use of legacy data, problem-solving and sustaining engineering on old programs, coordination of key characteristics up and down the supply chain, and emergence of new design methodologies alongside the old ones.

## Benefits

- Tools and methods to identify critical information needed to support important transactions.
- Improved learning curve and first time capability in manufacturing.
- Increased attention early in the design process to factors that will affect downstream performance.
- Faster problem-solving, better root cause analysis, and fewer change orders.
- Reduced cost and improved quality.

## Status

*Active*
*Start date: June 1994*
*End date: January 1998*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Massachusetts Institute of Technology*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Fast and Flexible Design and Manufacturing Systems for Automotive Components and Sheet Metal Parts

**Contract Number: F33615-94-C-4428 ALOG Number: 1250**

## Statement of Need

This project aims to improve key processes in the auto industry by following a bottom-up process. At the same time, it will deepen understanding of the top-level concepts of agility. Automotive components and assemblies are procured through a long process of requirements specification, customer-supplier negotiation, and a web of parts and tooling suppliers. Crucial information necessary for part fitup and product performance can be lost in this web, necessitating extensive problem-solving activities. Speed and flexibility can be improved by examining both the problem-solving processes and the underlying customer-supplier relations. This program is being coordinated with a parallel one in the aircraft industry (Contract Number: F33615-94-C-4429, Fast and Flexible Communication of Engineering Information in the Aerospace Industry) to provide cross-fertilization, leveraging of common research activities, and adoption of best practices from both industries.

## Approach

Fast and flexible business activities are characterized by: organizing for change, virtual partnerships, valuing knowledge and skills, and enriching the customer. This project aims to deepen understanding of these characteristics by studying specific assemblies built for and obtained from other companies. The methods being used are process mapping to identify crucial transactions between people and companies, linking transactions to clusters of specific engineering data called features, identifying transactions that do not add value, identifying and inserting missing transactions, and speeding up the processes by providing computer tools and database access that connect people and their transactions to engineering features.

Automotive items are highly engineered, made in mid to high volumes, and subject to intense regulation. Items being studied include sheet metal body assemblies and machined power train assemblies made for domestic and foreign customers. Each kind of customer has different needs and suppliers. Firms must convert requirements to engineering terms quickly and find the right suppliers or in-house manufacturing capabilities. Reduced problem solving transactions, better use of capital equipment, and faster reaction to new technologies are needed. Conditions observed include extensive problem-solving and the need to adapt old methods to new technologies and customers.

## Benefits

The benefits of this effort include:

- Better fidelity in translating customer requirements into engineering specifications.
- Tools and methods to identify critical information needed to support important transactions in customer-supplier interactions.
- Improved use and flexibility of existing high-volume capital equipment.
- Increased attention early in the design process to factors that will affect downstream performance.
- Faster problem-solving, better root cause analysis, fewer change orders, and faster time to market.
- Reduced cost and improved quality.

## Status

*Active*
*Start date: June 1994*
*End date: January 1998*

## Resources

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*DARPA Funded*

*Contractor:*
*Massachusetts Institute of Technology*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Flexible Environment for Conceptual Design

**Contract Number: F33615-96-C-5617 ALOG Number: 1484**

## Statement of Need

The objective is to develop and demonstrate an integrated set of flexible engineering analysis and design tools for supporting conceptual design of complex engineering systems. This project seeks to build a computer environment which can tightly integrate analysis across multiple disciplines. It will have the flexibility to let the analyst quickly explore new opportunities as they arise by making it as simple as possible to extend and/or modify analysis models.

## Approach

This effort will include research and development in design and analysis methods, with particular emphasis on: constraint management and non-linear solution methods including enhancements to the functionality of "Design Sheet"; implementation of new and enhanced methods in software for providing distributed access to the conceptual design tools and their models; and, investigation of techniques for integration of the resulting prototype software with other existing commercial tools used by designers. Challenging design exercises on Department of Defense relevant systems will be undertaken, in conjunction with the Navy Aegis LEAP (Lightweight Exo-Atmospheric Projectile) and the U.S. Air Force TAV (Trans-Atmospheric Vehicle) programs, using the integrated prototype software to evaluate its capabilities and limitations.

## Benefits

An advanced design environment based on constraint-based reasoning that, within a given time window, allows for an order of magnitude more design alternatives to be considered during the early stages of a design program. This environment will provide unique support for multi-disciplinary trade-off analyses and Design-to-Cost studies. Tools developed in this program are focused on the earliest stages of the design where the value of a good design decision has the greatest leverage.

## Status

*Active*
*Start date: June 1996*
*End date: April 1999*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Rockwell International Corporation*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Flexible Environment for Conceptual Design, Geometric Modeling and Analysis and Assembly Process Planning

**Contract Number: F33615-94-C-4426 ALOG Number: 1245**

## Statement of Need

In the earliest stages of Integrated Product/Process Development (IPPD), the capability is needed to easily evaluate the performance, cost, manufacturability and reliability of candidate designs. The ability to easily explore and analyze a wide range of factors is particularly important in the design and manufacture of electromechanical assemblies. The overall performance, cost and reliability of these assemblies are driven by the integration of knowledge and methods from a wide range of engineering domains (mechanical, optical, electrical, materials, etc.), manufacturing processes (machining, sheet metal forming, wirebonding, welding, plating, etc.), and testing during assembly (electrical, mechanical, optical, vacuum, etc.). Existing commercial design systems do not provide this capability. Design research efforts addressing this issue have been very limited and have either addressed very small design problems or have only provided limited qualitative results of realistic problems. The objective of this effort was to develop and demonstrate an integrated set of generic engineering analysis and design tools for both defense and commercial products. This was accomplished by integrating new and existing commercial off-the-shelf (COTS) software to provide an environment suitable for exploration and rapid analysis of a wide range of design variables with particular emphasis on evaluating the overall performance, cost and reliability of electromechanical assemblies.

## Approach

This program developed a prototype design system that supports multiple linked representations along with unique analysis and generative planning modules. It coupled a parametric model-based design representation (which is most appropriate during conceptual design and for integrating multiple disciplines) with a geometrically centered design representation. It provides a powerful analysis engine for use with the parametric model and provides a rich set of modules for displaying and analyzing the design using a geometric representation. In order to produce good process flow plans, a decision-theoretic planner, being developed as part of the Defense Advanced Research Projects Agency/Air Force Transportation Planning Initiative, was extended and linked to the geometrical modeler. The development of this environment for electromechanical IPPD was undertaken with the active participation of domain experts and system users. A unique combination of design researchers, commercial design tool providers and system users ensured that the technology was developed in a manner suitable for commercialization.

## Benefits

This program extended existing commercial engineering analysis and design tools in order to demonstrate the concept and measure benefits.

## Status

*Complete*
*Start date: October 1994*
*End date: January 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Rockwell International*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Improving Manufacturing Processes in Small Manufacturing Enterprises

**Cooperative Agreement Number: F33615-94-2-4418 ALOG Number: 1212**

## Statement of Need

According to a survey conducted by Minnesota Technology Inc., of Minnesota's 8,700 manufacturers, approximately 1,200 firms, ranging in size from 10 to 1,000 employees, are prime or subcontractors for DoD contracts. The Minnesota Department of Trade and Economic Development (DTED) estimates that nearly 30,000 defense related jobs were lost in Minnesota between 1987 and 1989, with 25,000 expected to be lost between 1991 and 1995.

In Minnesota, job losses were mostly in defense-related machinery and computer equipment manufacturing. Across the state, employment in this sector declined by nearly 10 percent from 1989 to 1991. In general, larger firms have resources that enable them to deal with such cutbacks. Small- and medium-size manufacturers lack the resources to respond adequately. To create the ability in small manufacturers to quickly respond to national security needs when an emergency arises, improvements in manufacturing processes must occur.

The primary objective of this project is to provide a productivity improvement waste reduction technique called the Manufacturing Improvement Process (MIP) to 36 small manufacturers in central Minnesota over a period of three years.

## Approach

MIP is based on a concept called Optimized Operations, which was developed by the 3M Company and used successfully in more than 200 projects in its own plants. Introducing MIP into a plant revolves around: 1) a six-month project designed to improve some aspect of plant operations; and 2) training company employees on subjects related to the success of the project. During the course of the project, company employees on the project team learn how to conduct MIP projects successfully so that after the Higher Education Manufacturing Process Applications Consortium (HEMPAC) leaves, MIP can continue. This iterative approach allows MIP to penetrate the company culture.

## Benefits

MIP: offers a model of problem solving that is applicable in a wide range of manufacturing situations; has preventive effects by routinely identifying potential problems and avoiding them before they arise; demonstrates long-term, ongoing benefits, as well as short-term gains; and integrates a common sense approach with a number of principles (Just-in-Time, Total Quality Management, etc.) that have been shown to be effective in improving productivity and quality.

## Status

*Active*
*Start date: March 1994*
*End date: March 1998*

## Resources

*Project Engineer:*
*Cliff Stogdill*
*AFRL/MLMS*
*(937) 656-9222*

*DARPA Funded*

*Contractor: Higher Education Manufacturing Process Applications Consortium*

*JDMTP Subpanel: Manufacturing and Engineering Systems*

# Integrated Knowledge Environment - Integrated Product Management

**Contract Number: F33615-96-C-5109   ALOG Number: 1462**

## Statement of Need

There is a need for innovative acquisition tailoring and alternative development processes for program management tools. Users need reference libraries that contain standards, handbooks, templates, guidelines, etc., which are accessible over local and wide area networks. There is also a need for tools that automatically produce tailored project plans and schedules from process model templates which contain systems engineering/configuration management activities for the various engineering and manufacturing disciplines. The objective of this project is to use the results of the Phase I research and extend the Integrated Knowledge Environment-Integrated Product Management (IKE-IPM) framework. The IKE-IPM is a framework for managing acquisition and sustainment projects and processes and for assessing the cost schedule, performance and risk associated with product development.

## Approach

The IKE-IPM tools will be based on the flexible framework of Phase I, which developed the capability to use integrated tools to enable project, process and product life cycle cost, risk and affordability analysis and management. The contractor developed the new IKE-IPM application, Object Czar (OZ). It provides capabilities to maintain individual and distributed work breakdown structures, organization structures, project structures, etc., and allows users to dynamically define object properties and immediately update them with values.

## Benefits

The IKE-IPM application will provide Virtual Manufacturing Enterprise users with a mechanism that will facilitate rapid development and distribution of planning and metric information, and facilitate the tracking of production status throughout the entire process. Oz allows users to:

- create collections that contain object instance relationships
- produce reports using rapid report generation capabilities
- define numeric object roll-up properties to determine cost, risk, weight, and other quantitative characteristics
- define object metric color roll up properties, to alert management of project status associated with processes and products
- link one or more views to any object in the hierarchy.

## Status

*Active*
*Start date: May 1996*
*End date: August 1999*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*Knowledge Base Engineering Inc.*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Integrated Process Planning/Production Scheduling

**Contract Number: F33615-95-C-5523 ALOG Number: 1368**

## Statement of Need

Although considerable progress has been made with respect to software technologies for process planning and finite-capacity production scheduling, very little attention has been given to issues of integration. In practice, process planning and production scheduling activities are typically handled independently, and are carried out in a rigid, sequential manner with very little communication. Process alternatives are traded off strictly from the standpoint of engineering considerations and plans are developed without consideration of the current ability of the shop to implement them in a cost effective manner. Likewise, production scheduling is performed under fixed process assumptions and without regard to the opportunities that process alternatives can provide for acceleration of production flows. Only under extreme and ad hoc circumstances are process planning alternatives revisited. This lack of coordination leads to unnecessarily long order lead times, increased production costs and inefficiencies. Increased manufacturing agility depends critically on the development of approaches for integrating these two activities. The objective of this effort was to develop, validate, and demonstrate an architecture for flexible integration of process planning and production scheduling.

## Approach

This effort was conducted in three phases. In Phase I the contractor developed an architecture to support interleaving of process planning and production scheduling functionalities in complex, highly dynamic, small-lot manufacturing environments. The architecture provided a common representation for exchange of process planning and production scheduling information, results and constraints; a control infrastructure for managing interaction between planning and scheduling modules; and coordination protocols for integration with outside information sources and systems.

Phase II developed a set of diagnosis/analysis modules to enable rapid end-user identification of potential problems or improvement opportunities, and capabilities for interaction manipulation of problem parameters and exploration of alternative "what-if" scenarios.

Phase III demonstrated and validated the IPPPS module. The contractor adapted and integrated two state-of-the-art technologies, an operational process planner and a finite capacity production scheduler to produce an integrated process planning/production scheduling module. Search control heuristics were test cases and provided capabilities for interactive interleaving of planning and scheduling tasks. In addition, evaluations were conducted to quantify performance gains.

## Benefits

The payoffs include enabling more efficient process plan development through early consideration of current resource capacity and production constraints, and greater optimization of production activities through direct visibility of process alternatives and trade-offs.

## Status

*Complete*
*Start date: April 1995*
*End date: March 1997*

## Resources

*Project Engineer:*
*John Barnes*
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*DARPA Funded*

*Contractor:*
*Raytheon Company*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Integrated Product/Process Development (IPPD) Simulation Model

**Contract Number: F33615-97-C-5129 ALOG Number: 1542**

## Statement of Need

The Manufacturing Technology Division aggressively pursues advances in manufacturing technology which have broad applicability to the affordability and performance of Air Force systems. The focus of this general topic is to allow opportunities for major breakthroughs in the areas of: Composites Processing & Fabrication, Electronics Processing & Fabrication, Metals Processing & Fabrication, Advanced Industrial Practices, and Manufacturing & Engineering Systems. New processing techniques, variability reduction tools, affordability improvements, and manufacturing simulation and modeling, are a few examples of the types of proposals that are desired. The emphasis is on innovation, the ability to achieve major advances, and defense/commercial applicability. The objective of this Phase I Small Business Innovation Research project is to develop a methodology for developing a dynamic simulation model of the Integrated Product/Process Development (IPPD) process.

## Approach

Decision Dynamics Inc. will develop a simulation tool that will provide a working prototype of the IPPD process and demonstrate its potential to assist U.S. Air Force program managers. The prototype model will:

- Create a structured theory of design decision-making that organizes available information and provides the means to collect, store and validate new information.
- Provide an operation methodology for testing present decision choices against the combined knowledge of the past in order to discover the most effective means of achieving engineering objectives.
- Furnish new insights into systems behavior and foster growth in the wisdom of program managers and design engineers to improve the quality of engineering decision-making.

## Benefits

The IPPD model will provide managers with a next-generation system for ensuring the most efficient management of complex product development projects. Adoption of this tool will move project management from reliance on outdated static methods since learning, schedule pressure, productivity and information flows will be included in the model. By using the model, managers will have the ability to evaluate qualitative measures and work quality in a dynamic simulation environment and to trace the impact of management decisions on a wide range of "what if" scenarios. Managers will also be able to improve the integration of new designs of products and their processes into the manufacturing life cycle.

## Status

*Complete*
*Start date: May 1997*
*End date: November 1997*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*Decision Dynamics Incorporated*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Internal Real-Time Distributed Object Management System

**Contract Number: F33615-96-C-5112 ALOG Number: 1442**

## Statement of Need

Data processing in the heterogeneous manufacturing information systems environment is cumbersome and time consuming. When users of the system require data from the network, they spend considerable time searching for the needed data, and even when they find this, it is often difficult to obtain the data in proper electronic form. The objective of this project was to establish a real-time communications service internal to Common Object Request Broker Architecture (CORBA) services, supporting the application user and external user sites. This Internal Real-Time Distributed Object Management System (IR-DOMS) had to resolve heterogeneous platform issues and provide the end user a seamless reliability capability to perform their jobs.

## Approach

The approach developed a commercial prototype software product called ORB_IT (Object Request Broker - Integration Technology), that facilitated "seamless" and "transparent" computing and data processing in a networked environment. Phase II used and enhanced the real time architecture established in IR-DOMS Phase I; each computing node is a client and also a server available over standard fiber channel based giga-bit and conventional networks. Object Management Group's (OMG) ISO Standards was used. The Object Request Broker (ORB) supports user applications and the Common Object Services Specifications (COSS) functions provides capabilities required by the ORBs across different computers. A Technical Review Board (TRB) and multiple beta implementation sites were established for IR-DOMS validation during the project. These sites demonstrated commercial components products and systems in their production facilities.

## Benefits

The ORB_IT technology is being transitioned as Fiber Express™, a recently introduced giga-bit network which can provide high bandwidth communication and real-time performance in a heterogeneous networked environment. The IR-DOMS technology can be used in any information systems environment and by any manufacturer to support the production of products for virtually any market including the process industries, automobile, petroleum, medical, aerospace, home and business appliances, electronics and utilities.

## Status

*Complete*
*Start date: March 1996*
*End date: December 1998*

## Resources

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*SBIR Funded*

*Contractor:*
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*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Joint Strike Fighter Technology Manufacturing Demonstrations

**Contract Number: F33615-95-C-5529 ALOG Number: 1359**

## Statement of Need

Current Lean Aircraft Initiative (LAI) research indicates a direct correlation between the degree of integration of cost and product/process data (design, manufacturing, supportability, and suppliers) and its use by integrated product teams. Companies with integrated cost and design databases experience better schedule and cost performance, while making more cost effective decisions. Related areas for improvement help to increase the accuracy of the cost data used to support decision making management practices, support decoupling cost from volume, and reducing cycle times. Near real time collection and feedback of cost data is cited as an enable of these capabilities. Development of these concepts requires consideration of business practice changes and infrastructure improvements. This program will develop and demonstrate improved cost/design methodologies which can be applied to the Joint Strike Fighter (JSF) during engineering and manufacturing development (EMD) to reduce life-cycle cost.

## Approach

The JSF Manufacturing Demonstration is developing procedures, business practices, processes and infrastructure improvements necessary to conduct product and process design using integrated cost and design data. The integrated methodologies and data will enable designers to quickly and accurately conduct design/cost trades, manufacturing process selection and cost estimation. A mini-demonstration applying the initial methodology and tools to a transmit-receive module was accomplished in January 1997. The following Phase I results have been demonstrated: 19 percent reduction in assembly recurring cost; 27 percent reduction in design/cost trade-off labor hours; 60 percent reduction in design/cost trade-off cycle time. A full demonstration is planned for 1998 using the methodology and tools on a subarray design with similar improvements anticipated. The methodology and demonstration results are available from the JSF Program office.

## Benefits

This effort will demonstrate transportable lean processes, practices and tool integration techniques for the JSF community. It will produce a validated methodology to reduce cost and improve schedule performance in time for widespread application within the JSF Engineering and Manufacturing Development (EMD) phase. Benefits include a potential reduction in JSF life cycle costs of four to six percent.

## Status

*Active*
*Start date: April 1995*
*End date: December 1998*

## Resources

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# JSF Manufacturing Capability Assessment Tool Set

**Contract Number: F33615-95-C-5527 ALOG Number: 1340**

## Statement of Need

The early consideration and management of manufacturing risk in technology development is critical to the Joint Strike Fighter (JSF) initiative. A manufacturing capability requirements (MCR) assessment already exists. The MCR process results in a detailed system-requirements, technology-process profile. This profile defines technology development and maturation efforts with recommendations to resolve identified manufacturing deficiencies based on analysis of collected information. However, a need exists to computerize this methodology and extend it to identify, quantify, and capture key manufacturing processes, critical characteristics, and capability indices.

The objective of this program is to develop and implement an approach which defines the format and content of JSF information used in the MCR process, computerizes the MCR assessment methodology, and extends the process. This extension will include, but not be limited to, six-sigma design concepts, process capability, process variability, critical characteristics, predicted first-time yield, and defects per unit. In addition, information collected during the assessment will be organized so a software toolset can be used in conjunction with the MCR methodology to perform a structured assessment of product and process maturity technology options for subsystems or systems.

## Approach

The program will use a series of mini-workshops involving all members of the JSF Manufacturing Capability Assessment Toolset (JMCATS) team. The members consist of government personnel and representatives from Boeing, GEAE, Hughes Radar and Communication Systems, Lockheed Martin, McDonnell Douglas Aerospace, Northrop Grumman, Rockwell Collins, and Texas Instruments. The objective of the workshops is to allow the members to develop an overall methodology and set of software requirements for JMCATS. The team members will also identify users at their companies to further develop the software prior to final release. Training for the users will accompany each release of the software. Three versions of JMCATS software will be developed with the final version available to all members of the JSF community.

## Benefits

The payoff of this effort is to develop and demonstrate a methodology and software toolset which will enable the early identification of manufacturing risk for JSF technologies. This will ultimately facilitate the development and documentation of product and process technologies with sufficient maturity to achieve JSF objectives.

## Status

*Active*
*Start date: April 1995*
*End date: December 1997*

## Resources

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# Large Scale System Simulation and Resource Scheduling Based on Autonomous Agents

**Contract Number: F33615-95-C-5524 ALOG Number: 1339**

## Statement of Need

Competitive pressures are moving manufacturers toward shorter product cycles, lower inventories, higher equipment use, and shorter lead times. As a result, the problem of scheduling and controlling the shop floor grows in importance. Manufacturing scheduling and control has traditionally been viewed as a top down process of command and response that relies on hierarchical models of the manufacturing enterprise. Control and scheduling software must handle the entire factory, and anticipate every circumstance that can arise. Changes in the configuration of the factory require changes in the control software. The central computer and database are a bottleneck that can limit the capacity of the shop, and constitute a single point of failure that can bring the entire system down. Unexpected events often require restarting the entire system, and in complex facilities it is common for the scheduling and control software to require restart several times per day. The objective of this program was to prove and demonstrate the utility of the autonomous agents concept as a paradigm for performing scheduling, real-time control, and large-scale factory simulations.

## Approach

Initial tasks of the program focused on the development of a factory floor scheduling simulation based on the autonomous agent paradigm. These tasks included the determination of relevant resource characteristics and the definition of agent rules to accurately model these characteristics. Resource rule development benefited from manufacturing process expertise provided by U.S. Army Rock Island Arsenal production personnel. Additionally, during the early phases of the program, the contractor developed a suitable simulation framework, leveraging CORBA compliant object structures, with which to run the agent simulations. As the initial scheduling simulation was assessed, refined and expanded to include additional resources, software tools automating the creation and maintenance of autonomous agents were developed and tested. These software tools led to a commercial product at program completion. The program culminated with a pilot implementation of the developed scheduler/simulation on the shop floor of the U.S. Army Rock Island Arsenal. The contractor provided training in the development and use of the agent-based scheduler, and quantified the scheduler's benefits in terms of enhanced agility based on actual shop floor situations encountered at Rock Island.

## Benefits

This work developed theory, tools and techniques to implement autonomous agent-based schedulers for use in large factories, and demonstrated/evaluated these tools and techniques to simulate aspects of production scheduling at the U.S. Army's Rock Island Arsenal. Autonomous Agent-based schedulers have the potential to enhance agility because they are less complex and more responsive to changes than are current conventional schedulers. The technology developed under this work can be easily applicable to a wide range of both military and civilian facilities.

This program resulted in: development of Cybelle Agent Infrastructure providing efficient platform/location independent intra-agent communication and agent migration capabilities; software development methodology for building multi-agent systems; agent-based Factory Scheduling Architecture for agenting factory activities and resources; development of agent to agent negotiation protocols; and development of Least Commitment Factory Scheduling software based on autonomous agents.

## Status

*Complete*
*Start date: April 1995*
*End date: April 1997*

## Resources

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*DARPA Funded*

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*JDMTP Subpanel:*
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# Laser-Based Reverse Engineering & Concurrent Systems

**Contract Number: F33615-96-C-5616 ALOG Number: 1453**

## Statement of Need

The Department of Defense fleet of aircraft has an average age of 25 years. Structural parts of these aircraft are in constant need of repair or replacement. The current practice involves several months, with a Computer Aided Design (CAD) expert, measuring the original part and creating a three-dimensional CAD model of it so that the replacement part can be machined. This process can be very time consuming and take the aircraft out of service for an extended period of time. DoD needs a faster turn around on the manufacturing of these parts so that the aircraft returns to service as soon as possible. Engineers from the Air Force Research Laboratory Manufacturing Technology Division are working with the Florida International University on a program which will try to develop a process in which laser scanners are used to reverse engineer the structural parts into CAD models which are then integrated with an existing concurrent engineering system to remanufacture these parts.

## Approach

The Laser-Based Reverse Engineering and Concurrent Systems project will generate three-dimensional CAD models of scanned structural parts. Engineers will then determine the error ratio between the scanned CAD model and the original drawings (if available), correct the errors found, then generate the Numeric Code (NC) needed for the automated machining of these parts.

This program hopes to demonstrate the use of laser scanners to speed the process. By scanning these aircraft parts, in just days rather than months, the three-dimensional CAD models could be complete and the part could be machined in a shortened time span. This program will attempt to prove that the use of laser scanners will help speed the process, will address a requirement for the different departments of DoD, and will also provide direction for the commercial industries.

The project is part of the historically black college and university (HBCU) and minority institutions (MI) effort. This provision of the United States Code has a goal for each of fiscal years 1987 through 2000 to award five percent of contract and subcontract dollars to small disadvantaged business concerns and HBCU/MIs and requires a separate goal, for each of fiscal years 1991 through 2000 as a subset of the five percent goal, for the participation of HBCUs and MIs.

## Benefits

A fully integrated reverse engineering and concurrent engineering system will provide the Air Force Logistics Centers an efficient method for manufacturing critical components.

## Status

*Active*
*Start date: February 1996*
*End date: July 1998*

## Resources

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# Manufacturing Assembly Pilot (MAP) Project

**Cooperative Agreement Number: F33615-95-2-5518 ALOG Number: 1362**

## Statement of Need

In large-scale mass production industries, such as the automotive and aerospace industries, agility depends on the efficient flow of material and material requirements up and down the supply chain. These large industries are moving toward the business strategy of flexible manufacturing including the concept of mass customization, agile material flow, and reconfigurable logistics which provide custom products. The ability of the lower tier suppliers to meet requirements, such as just-in-time delivery and reconfigurable electronic data interchange, will become a critical factor for cost effective and agile manufacturing capability. The goal of the MAP was to improve the synchronization, integration, and flexibility of the automotive supply chain through the adoption of new technologies and business practices.

## Approach

This effort was organized into three phases. The first phase developed a consensus on the improvements to be made in business practices and systems. This agenda was achieved by first modeling the existing processes at all levels of the supply chain followed by planning, modeling and simulation of the proposed solutions and metrics for evaluating improvements in performance at both the firm and supply chain level. A benchmarking exercise looked at leading practices in other industries as well as in the automotive industry. A best practices guideline was published that covered new business practices for processing order releases, schedule notification and shipping notification; communication standards; electronic data formats; and business case justification.

The second phase supported the demonstration, implementation, and preliminary evaluation of new business practices and systems. During this phase, the team implemented various aspects of the best practices guideline developed during Phase I. A testbed was established to evaluate and demonstrate various technical approaches to communications, order processing and scheduling. A training program was established to assist team members in preparing their personnel. An approach was established to evaluate the performance of the team against similar supply chains and their own historical performance. The second phase resulted in the implementation and evaluation of the supply chain's improvements in performance, and was the basis of exporting new business practices and systems to other supply chains.

The final phase fully evaluated and documented the project and put in place the means to deploy the results of this effort to many other supply chains in the automotive and other industries. The best practices guideline was revised to reflect the results of actual implementation and evaluation. A business case was developed for use by small supplier firms to justify adoption of the best practices.

## Benefits

The MAP project was able to reduce the time it took to go from one of the Big Three automobile companies down to the lowest tier of the supply chain from 28 days -- or almost one week per tier -- to 11 days, a 58 percent reduction. Lead time was reduced by 58 percent, inventory turns improved by 20 percent and error rates were reduced by 72 percent. The use of an electronic system of commerce has also increased the accuracy of that information. Distorted or truncated information can increase costs in the form of "just-in-case" inventories, premium freight and unplanned production changeovers. The study found that if the results of the MAP project were implemented throughout the entire U.S. automotive supplier network, the "expected" savings due to improved communications would be $1.07 billion, or $71 per vehicle.

## Status

*Complete*
*Start date: January 1995*
*End date: March 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*Automotive Industry Action Group*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Manufacturing Simulation Driver

**Contract Number: F33615-96-C-5609 ALOG Number: 1481**

## Statement of Need

The overall objective of the Rapid Design Exploration and Optimization (RaDEO) program is to develop engineering tools and information integration capabilities that could be used to evaluate an order of magnitude more design alternatives than is possible today in an attempt to optimize several product characteristics, and quickly prototype complex products and processes. As part of RaDEO, the objective of the Manufacturing Simulation Driver (MSD) program is to develop, validate, and demonstrate the use of Factory Simulation to explore and compare alternative design approaches, alternative workflows, outsourcing of specific operations, and alternative internal and external factory utilization.

## Approach

Factory simulations will be created using the STEP standard as a foundation for product/process modeling, manufacturing knowledge bases and simulation engines. The MSD program will build extensions to the STEP standard that enable the capture of a manufacturing enterprise model to the level where descriptions of processes and resources are robust enough to support driving an enterprise level simulation. The STEP model will lead to the development a software interface to a set of Deneb simulators. The program will conclude with a concept demonstration.

## Benefits

The MSD program will evaluate simulation metrics, continuous product design refinements, as well as timely and cost effective design and production methods.

## Status

*Active*
*Start date: April 1996*
*End date: February 1998*

## Resources

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# MEREOS - A Product Definition Management System

**Contract Number: F33615-95-C-5519 ALOG Number: 1370**

## Statement of Need

Almost all manufacturing enterprises producing complex products develop separate engineering, manufacturing, and logistical or field support product definitions, in order to support various engineering, manufacturing and maintenance activities. Each of these configurations inevitably differ from one another both in form and in content. These differences mark the presence of certain kinds of relations that span bills of material (BOMs). The task of reconciling multiple BOMs for a product involves identifying components that stand in counterpart relations across them, and characterizing the properties of those relations. Establishing counterpart traceability is essential for managing engineering change. Managing this process is possibly the most complex and costly activity in a manufacturing enterprise. The multiple BOM phenomenon exacerbates this already difficult problem, since the impact of changes to a component in one BOM must be determined for all of its counterparts in any other BOMs. There is a direct linkage between the multiple BOM reconciliation problem and the high costs and long lead times associated with engineering change. Product data is the centerpiece of manufacturing enterprise information assets.

The objective of the MEREOS project is to develop a product definition management system based on PACIS®, a next-generation ANSI/ISO database management system. The goal of the system is to solve the multiple bill of materials reconciliation problem in large-scale, complex product manufacturing environments. The specific objective is to provide end users with the ability to define, modify, query, and automatically maintain relationships between several distinct BOMs, specification trees, and functional structures for a single product, where the information involved is stored in databases.

## Approach

The approach for solving the multiple bill of materials reconciliation problem involves the development of a product definition management system specifically designed to automate counterpart traceability across distinct BOMs for a given product. This system is designated MEREOS and will be implemented as an application hosted by PACIS®, a database management system based on the ANSI/ISO 3-schema architecture currently under development. Three broad capabilities will be supported with MEREOS: product structure definition and management; process structure definition and management; and technical document creation and integration. Each of these capabilities will be delivered as an integrated suite of functions within a single application system running on UNIX® workstations and employing extensive interactive graphical interfaces.

## Benefits

MEREOS can be used in a number of different ways. A systems engineering organization could use it to support automated requirements analysis, decomposition, and traceability. A program management office or product group could use it as the core of a status accounting system. Manufacturing or logistics engineering groups could use the system as an application for defining "as-planned" or "as-supported" structures whose elements must be traceable to "as-designed" components and functional requirements. Finally, an information systems organization could use the system as a tool for update dissemination and database integrity maintenance in environments that have different system managing different versions of product structures.

## Status

*Active*
*Start date: December 1994*
*End date: December 1998*

## Resources

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# Minnesota Consortium for Defense Conversion

**Cooperative Agreement Number: F33615-94-2-4417 ALOG Number: 1220**

## Statement of Need

Recent surveys indicate that at least 1,100 Minnesota firms are primes or subcontractors for the Department of Defense. Defense cutbacks have already led to employment losses in Minnesota, particularly in primes such as FMC Corp., and Alliant Techsystems. The state projects additional job losses at wages averaging $38,410 -- a wage that is 66 percent higher than the average state salary. Just as troubling is the potential loss of expertise critical to supporting future U.S. competitiveness. Minnesota is nationally recognized as a center for high precision, high tolerance machining -- 25 percent of which is currently dedicated to the defense market. Maintaining this manufacturing capacity and adapting this expertise to new market opportunities must occur if the U.S. is to develop critical technologies and new products.

The major objectives of the consortium are: to support the ability of Minnesota's defense suppliers to develop new commercial and defense dual-use products and markets; to explore the feasibility of an electronic network; and to obtain the information and knowledge to maintain the manufacturing capacity of Minnesota defense companies.

## Approach

The approach conducted by the consortium includes:

- Form a membership organization.
- Explore the feasibility and possible establishment of an electronic network.
- Assist suppliers in developing dual use and new products.
- Facilitate joint proposals among suppliers for commercial and defense markets.
- Establish methods and metrics for evaluating the effectiveness of the consortium.
- Disseminate information on lessons learned to other TRP programs.

## Benefits

The Minnesota Consortium for Defense Conversion supports the ability of Minnesota's DoD suppliers to develop new products and to compete in new defense and commercial markets.

## Status

*Active*
*Start date: March 1994*
*End date: March 1998*

## Resources

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# Missile Industry Supply Chain Technology Initiative (MISTI)

**Contract Number: F33615-96-C-5115 ALOG Number: 1522**

## Statement of Need

Fifty percent of missile production cost lies in the supply chain below the prime contractor level. Large percentages of the time required for missile acquisition are consumed configuring and utilizing that supply chain to find the necessary information to design, produce, and support parts and services that meet missile system requirements. Attempts to introduce new technology (e.g., Electronic Data Interchange (EDI)) to improve the way in which the supply chain functions have been frustrated by: (1) the size, complexity and diversity of the supplier population (a mix of high and low levels of technological sophistication); (2) the inflexibility of EDI standards; (3) the inadequacies of the tools supported by those standards; and (4) the anticipated need to accommodate low-volume, multi-missile production in the future. The objective of the MISTI program is to define, develop, implement, demonstrate, and quantify the benefits of a set of innovative, high-impacting tools and technologies which utilize the Internet to create an agile integrated missile supply chain. Technologies, services, and applications resulting from work will be integrated and deployed into a series of metricized alpha tests to demonstrate their widespread applicability and impact for efficient supply chain integration in support of the AM3 goals of significant missile sector acquisition cost reduction, time compression, and quality improvement.

## Approach

The contractor will: develop the basic technology necessary to create and maintain a universal catalog protocol (UCP) and a universal catalog gateway (UCG) infrastructure to facilitate creating, populating, integrating, and maintaining distributed web-based mega catalogs; build and populate an initial set of missile industry catalogs; create a suite of key engineering and strategic planing applications which will access supply chain information in the catalogs via UCP/UCG; pursue an aggressive technology transfer and commercialization plan to ensure widespread availability of technologies, services, and applications.

## Benefits

Using the UCG and an extensible suite of key UCP/UCG-compliant applications developed or adapted by the SAIC Team, missile contractors will be able to: (1) rapidly configure a supply chain; (2) locate, select and customize components; (3) search and determine best matches among components available in the supply chain and any set of designer-specified requirements, while automatically verifying the associated integration requirements; (4) dynamically create a Web-distributed federated object model (FOM) of an evolving missile product design; (5) generate product realization plans (Bills of Processes) for alternate designs; (6) rapidly estimate the total acquisition cost increment associated with a P3/supplier choice; (7) exchange models, simulations and production data; (8) integrate and manage design trades across the supply chain; and (9) launch COTS and contractor-specific engineering, production and business applications that utilize design and production data from the supply chain.

## Status

*Active*
*Start date: November 1996*
*End date: March 1999*

## Resources

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*DARPA Funded*

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# Mixed Signal Test (MiST)

**Cooperative Agreement Number: F33615-95-2-5562 ALOG Number: 1346**

## Statement of Need

The availability of submicron CMOS technology, precision bipolar capability, and multi-chip modules (MCMs) continues to increase the complexity of analog and mixed-signal designs. Along with this increase in density and complexity come several challenges in developing test prototyping, production, and trouble shooting.

The first challenge relates to complexity, density, lack of access to constituent ICs, and the need for interconnect testing. The second has to do with the specification-driven nature of test procedures for mixed-signal circuits which poses two major problems. First is that under-specified systems specification testing results in test programs with insufficient analog fault coverage for high quality products. Second is the inability to diagnose an out-of-specification system due to a lack of connection between specifications and component failures. Finally, there is the challenge of having to synchronize digital and analog test resources to test a mixed-signal circuit.

The objective is to develop a set of integrated design and test tools for the development of mixed signal multi-chip modules and printed circuit boards.

## Approach

In this program, the contractor proposes to solve the above problems by expanding the capability of the IMS MCM Test Development System (TDS) to incorporate specification testing in the design hierarchy and relating it to the underlying analog fault models. Mixed-signal scan and multiplexing techniques will also be introduced into the design-for-test process to enhance accessibility. The development and demonstration of control and observation test structures for analog devices will also be accomplished.

## Benefits

The availability of test development tools and technologies integrated with mixed signal design environments will significantly decrease the test development efforts associated with production and support.

See the MiST Consortium Homepage for more information: www.ee.washington.edu/mad/mist/mist.html

## Status

*Active*
*Start date: September 1995*
*End date: February 1999*

## Resources

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# ModelQuest Software Process Quality Assessment

**Contract Number: F33615-95-C-5544 ALOG Number: 1419**

## Statement of Need

Statistical network modeling technology enables the Department of Defense and industry to automatically generate powerful models of software, product, and/or process quality that are tailored to specific organizations based on their historical metrics and defect data. Computer software programs must be reliable and free of defects, to avoid costly, life-threatening errors. AbTech Corporation has developed a superior ModelQuest (MQ) Metrics product which automatically produces expert evaluations of software quality and generates tailor-made computer models. AbTech's MQ was used as the baseline tool set for the project and was integrated with a mix of other advanced computing technologies to form the hybrid environment needed to develop a superior assessment model.

## Approach

The models use mathematical functions and the self-learning properties of neural networks to predict software errors. The models are powerful feed-forward networks of mathematical functions and a single network can use several different types of functional nodes. MQ Metrics analyzes software source codes, produces statistics and metrics and provides measures of what these mean, produces exceptionally accurate reliability and maintainability predictions, assesses source code quality, identifies significant variables and generates reports and graphs. Some of these reports identify the quality of each module as well as the key factors impacting the probability of a given module having significant defects. This predictive capability enhances software quality control, improves efficiency, and optimizes resources. MQ Metrics includes source code metrics generation, reliability prediction and maintainability evaluation software. MQ Expert is an intelligent system development tool which integrates MQ and database management, visual analysis, report generation, and expert system software, to enable users to obtain a variety of reports and visual information with which they can analyze their software quality and development process.

## Benefits

The use of this unique modeling approach for software quality assessment results in improved quality by identifying and analyzing defective and high-risk software products and processes early in the development and production cycle and addressing the underlying causes for defects. The resulting predictive capability provided by this tool has created a growing customer market of data mining tools and models. AbTech developed and commercialized five new products during this program, and variations of those tools are being tailored for other government projects. One program with the NASA Johnson Space Center and with the Air Force Phillips Laboratory, will develop a variation of AbTech's general modeling tool, ModelQuest Expert, which will automate the development and implementation of statistical network models to detect anomalies in the Space Shuttle and satellite telemetry. For the Army Artillery Research Development and Engineering Center at Picatinny Arsenal, AbTech successfully demonstrated the application of ModelQuest statistical networks to verify sensor performance, detect and isolate faults and estimate performance degradation on the M109 Howitzer diesel engine. Nortel Inc. is using ModelQuest to develop models for a decision support system for assessing risk to improve telecommunication switching network software service quality. Nortel switches and embedded software are used around the world by AT&T, MCI and Sprint.

## Status

*Complete*
*Start date: October 1995*
*End date: July 1997*

## Resources

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# Multi-Chip Module Infrastructure Development

**Contract Number: F33615-93-C-5315 ALOG Number: 135**

## Statement of Need

Most multi-chip module (MCM) manufacturing has used materials, equipment, and processes originally optimized for the integrated circuits, printed circuit board, or hybrid industries and later modified for MCM fabrication. This adaptation of existing equipment and processes, while demonstrating the performance capability of MCM technology, resulted in low volume production capability, high unit costs and significant marketplace resistance. Since high yields and reduced handling costs are critical drivers for low-cost manufacturing, the use of large format (>400 mm x 400 mm) processes, intelligent manufacturing techniques and rigorous cost analyses were viewed as essential. While a wide range of unit processes were considered for development, those having widespread applicability over the broad scope of the MCM industry (or perhaps beyond it, such as into flat-panel display manufacturing), or having particularly high leverage on MCM costs, capabilities or yields were of greatest interest. The objective of this effort was to develop the infrastructure design and test automation tools necessary for the widespread use of MCMs. This effort developed commercially available design and test automation tools necessary for designers of MCMs to more accurately and cost effectively design MCMs.

## Approach

The approach was to extend current electronics computer-aided design and computer-aided test tools to support MCM design activities. Specific areas of work were test pattern generation, logic synthesis, and AC and DC parametrics analyses. E-Systems, the prime, provided user requirements and demonstrated developed tools on MCM designs.

## Benefits

Many of the CAD tools developed by this project are now available as commercial products from Cadence Design Systems, Viewlogic (Quad Design), and Teradyne (Victory Products). A final report detailing many of the new unique CAD tools available for complex MCM design, AC/DC parametric analyses, and test creation for boundary scan and non-boundary scan MCMs is now available.

## Status

*Complete*
*Start date: December 1992*
*End date: December 1996*

## Resources

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*DARPA Funded*

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*JDMTP Subpanel:*
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# Multiphase Integrated Engineering Design (MIND)

**Contract Number: F33615-96-C-5621 ALOG Number: 1479**

## Statement of Need

The overall objective of the Rapid Design Exploration Optimization (RaDEO) program is to develop engineering tools and information integration capabilities that could be used to evaluate an order of magnitude more design alternatives than is possible today in an attempt to optimize several product characteristics, and quickly prototype complex products and processes

As part of RaDEO, the objective of this project is to provide for the development of key enabling technologies and tools to support integrated products from early stage design through manufacture for electromechanical parts.

## Approach

The development of enabling technologies such as Design Assistants (DAs), Design-Area Encapsulations (DEs), Linked Design Alternatives, Flexible Elements, and Early Stage Features will support the transition from functional specifications to early stage assembly, shape, and engineering design through detailed design and manufacturing. This will dramatically extend the concepts of feature-based, parametric design to earlier phases and new domains.

## Benefits

This program will help reduce the design and manufacturing cycle for complex electromechanical devices.

## Status

*Active*
*Start date: March 1996*
*End date: March 1999*

## Resources

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*DARPA Funded*

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*JDMTP Subpanel:*
*Manufacturing and*
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# National Industrial Information Infrastructure Protocols

**Cooperative Agreement Number: F33615-94-2-4447 ALOG Number: 1227**

## Statement of Need

The virtual enterprise is the bold, new concept of many small independent companies (or parts of large companies) joining together to work as a single enterprise on a specific project. In this way, widespread companies with their respective areas of expertise can complement one another and join forces quickly to create and manufacture superb products at very competitive prices. This synergistic process is believed by many experts to be the organizational concept the U.S. must exploit to create increased worldwide demand for a new generation of superior American products and generate millions of additional U.S. manufacturing jobs. A major inhibitor to implementing this concept is the lack of a national computer infrastructure. The NIIIP program will overcome this inhibitor. NIIIP will consolidate, rationalize, and integrate a set of standards upon which applications will be built and virtual enterprises will be formed. Jobs will be created in the computer industry and in the organizations which participate in virtual enterprises.

## Approach

The National Industrial Information Infrastructure Protocols (NIIIP) Consortium is a team of organizations that has entered into a cooperative development agreement with the U.S. government to develop open industry software protocols that make it possible for manufacturers and their suppliers to effectively interoperate as if they were part of the same enterprise, even though many of these interactions are unscheduled, occur between both sophisticated and relatively unsophisticated users who utilize a wide range of computer systems, operating environments, and business processes.

These protocols will enable a new form of collaborative computing in support of highly efficient and globally competitive "Virtual Enterprises."

## Benefits

The NIIIP Consortium approach converged commercial off-the-shelf standards and tools, the skills of the team members (the leading practitioners of each of the relevant technologies), to offer a powerful solution for the virtual enterprise. A summary of the benefits of this solution include:

- Enables organizations to quickly form a Virtual Enterprise on an ad hoc basis.
- Provides means for rapid reaction and reduced design cycle times.
- Overcomes inhibitors to information accessing, sharing, and communicating.
- Permits users to focus on product solutions, not computer constraints.
- Includes all sizes of companies from the smallest to the largest.
- Increases efficiency and improves quality of design and manufacturing of products, leading to increased world demand and more U.S. jobs.

## Status

*Active*
*Start date: September 1994*
*End date: June 1998*

## Resources

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*JDMTP Subpanel:*
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# Net Shape Casting Production Machine

**Contract Number: F33615-97-C-5123 ALOG Number: 1546**

## Statement of Need

Under Phase I, Metal Matrix Cast Composites, Inc. developed a process to integrate design and solidification modeling into a near-absolute net-shape casting production machine. This research is novel in that components begin as CAD solids models and are sent via a communications link to Oak Ridge national Laboratory for FEA and solidification analysis. The data is then sent back to MMCC to a CNC for mold creation and finally cast to near-absolute net-shape; at MMCC. The changes in process and using the ISO-STEP standards is a first step in the integration of mechanical processes, materials and computer technology standards. This will enable a move towards the technology shift in manufacturing required to advance the state of the art and move manufacturing in the direction of a major paradigm shift.

The objective is to use the Advanced Pressure Infiltration Casting (APIC™) process as a low cost method of manufacture for cast metal matrix composite components.

## Approach

A liquid-cooled hollow brake rotor for flight-line tow tractors is the component which will be developed to demonstrate the technology during the first year. A bench scale water vaporization cooled aircraft brake rotor will be used to demonstrate rapid redesign/reengineering features of the Net Shape Casting System, during the second year. MMCC will install SDRC's Finite Element Analysis software to analyze stress and strains throughout a part, so part designs can be readjusted to best utilize a composite's properties and optimize these for minimum weight.

## Benefits

The Air Force will benefit from having available new technology that can decrease the delivery time for parts to the point of need in the field. This work will lead to reductions in cost of producing both simple and complex formed products. MMCC is involved in licensing APIC technology to the automotive industry and heavy equipment manufacturers. Greater integration will make the process more flexible and prototyping will be more rapid and more representative of true large scale manufacturing. Applications include automotive, aerospace, marine, and sporting goods. These applications all require high performance materials at low cost. The Defense Advanced Research Projects Agency and the Navy have awarded a contract to develop this technology as an on-board part production facility. ManTech will participate in this and is studying Air Force impact of this technology and its applications for small parts production.

## Status

*Active*
*Start date: April 1997*
*End date: July 1999*

## Resources

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# New England Supplier Institute

**Cooperative Agreement Number: F33615-94-2-4424 ALOG Number: 1228**

## Statement of Need

The Corporation for Business, Work, and Learning is leading a six-state, industry-driven consortium, the New England Supplier Institute (NESI), in a pilot program which is identifying, coordinating and delivering technology deployment services to the region's supplier base.

## Approach

NESI helps small- and medium-sized firms keep pace with the requirements of their customers, with changing technologies, and with product/market requirements. Services are delivered in New England through local partners and offer a portfolio of tools and techniques that can be uniquely targeted to the needs of an individual supplier. NESI also builds mentoring partnerships between suppliers and customers. By its third year of operation, NESI had served approximately 750 firms.

## Benefits

- Improve competitiveness of defense related OEMs and suppliers in six New England states.
- Diversify business base of defense dependent subcontractors.
- Establish a model for coordinating services across state boundaries.

## Status

*Complete*
*Start date: August 1994*
*End date: December 1998*

## Resources

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# PDES Application Protocol Suite for Composites

**Contract Number: F33615-91-C-5713 ALOG Number: 177**

## Statement of Need

The need to support systems such as the C-17 and the F-22 creates an imposing burden on the existing capability of Air Logistics Centers (ALCs) (and also prime and subcontractor) to accept, manipulate, transfer, and share digital product data. In the few cases where the Air Force transfers data, the methods are labor intensive and often outmoded. If so much as a software version is changed, the ALCs must completely redesign their data exchange techniques.

The objective of this project was to develop and demonstrate a product definition information model sufficient to represent and exchange information to design, analyze, test, produce, assure the quality of, and repair composite parts as typified by aircraft composite structural components. This project initiated and established the procedures required to provide a neutral data format for composite structure so that the composite product data can be digitally transferred between industry producers and government agencies. This resulting neutral format supports the Integrated Product Development (Concurrent Engineering) principles, reduces product delivery time, and reduces the cost of Air Force weapon systems. This program provided a neutral and unambiguous data exchange technique that improved the data management capability within the aircraft structural composites component community.

## Approach

The program was conducted in three phases and focused on the product class typified by composite airframe structural components. The product data required to design, analyze, test, produce, and assure the quality of these components formed the basis of this program. Production requirements were measured by the completeness of the data to fully satisfy the requirements of Level 3 production drawing packages as specified in MIL-T-31000.

Maintenance and disposition of composite components were not a primary focus addressed in the program. Also, the program did not directly address the manufacture of composite fibers, tapes or plies, though the product data required to define them for use in the manufacture of parts was addressed in the program.

## Benefits

The results of this project helped establish the costs, benefits, and risks of using this neutral format. This project also defined the framework for application specification implementation procedures to be used in making the Product Data Exchange using STEP (PDES) specification supportive of the full spectrum of manufactured parts and procedures throughout the product life cycle. This effort resulted in the growth and maturation of PDES and endorsed its use as a national standard. Benefit analysis has shown that PAS-C products provide an 18 percent reduction (average) in touch labor necessary to create and maintain engineering data for a military weapon system. When fully implemented on a major DoD weapon system, savings of $2 million to $4 million annually is expected for the life of the system.

## Status

*Complete*
*Start date: July 1991*
*End date: February 1997*

## Resources

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# PDES Application Protocols for Electronics

**Contract Number: F33615-91-C-5718 ALOG Number: 179**

## Statement of Need

The lack of a common product data exchange standard and methodology for product data exchange is considered to be of critical importance for electronics vendor survival, and for Air Force support of complex electronics. There are several electronics data standards which provide different electronics product data coverage in support of different development and life cycle support activities. The development of a common approach to the use of these electronics data standards during the development and support of a product and for the representation of critical product data items provides the common thread which is needed to bring about the wholesale use of product data exchange within the electronics development and computer-aided design (CAD) communities.

The objective of this project was to develop Product Data Exchange using STEP (Standard for the Exchange of Product Data Model) (PDES) application protocols sufficient to represent, exchange, and use information for the design, manufacture, integration, and test and reprocurement of electronics. This project also demonstrated a selected portion of the developed application protocols representing test and integrated diagnostics information.

## Approach

The Air Force was interested in the formation of a set of allied applications. These were used to: focus on a limited set of functions and document the required functionality in a human interpretable functional model; focus and document the resulting information needs in a context dependent on the human interpretable information model; develop a computer interpretable information model and associated mappings; assure the development of appropriate conformance and validation criteria; and populate a data base substantiated with product data representing an electronics product.

By allowing for the potential to integrate related application protocols, a useful and implementable application protocol set for electronics emerged. It was essential to maintain close coordination with the standards-making bodies and the product data community at large as an integral part of developing the application protocol set.

## Benefits

This information modeling approach has been adopted by the current industry Electronics CAD CAM Exchange (ECCE) project. This joint project between the EIA and IPC will bridge the gap between printed circuit board CAD and CAM for first pass manufacturing success. A final report detailing the unique information modeling approaches taken and now adopted by many industry efforts is now available. More information is also available on the PAP-E homepage at www.inmet.com/pape.

## Status

*Complete*
*Start date: September 1991*
*End date: December 1996*

## Resources

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# Process Capability Methodology for Integrated Product Development

**Contract Number: F33615-93-C-4325 ALOG Number: 1139**

## Statement of Need

Product definition techniques for setting part tolerances used in fabrication fail to achieve part fit, form, and function in the assembly process. Use of blanket tolerances and lack of attention to tolerance analysis are major contributors to poor control of manufacturing costs. These problems increase procurement costs, slow product delivery, and result in product quality problems.

A significant roadblock to optimizing part tolerances is that the engineer does not have the necessary manufacturing process capability information during the design phase. Developing detailed manufacturing and assembly tooling process capabilities is critical to proper tolerancing and part design. In addition, any methodology for assessing process capability must also be compatible with traditional statistical process control (SPC) initiatives.

The objective of this program was to maximize part fit and manufacturability by accounting for manufacturing process capability during product design, setting sensible part tolerances and applying ANSI Y14.5 Geometric Dimensioning and Tolerancing (GD&T) to improve communication.

## Approach

In order to assess manufacturability, the contractor used a computer software program called variation simulation analysis (VSA). VSA provided the capability to assign part tolerances, and with the help of a computer-aided design model, to associate process capability data with part features. This variability has a direct correlation to meeting system performance requirements. VSA allowed for simulated production capability information, called surrogate process capability data, which must be collected from processes that make part features similar to those that will be designed in a new aircraft.

With VSA, multiple design, fabrication, and tooling proposals will be concurrently simulated and evaluated. The product definition team will have the option of selecting the design, fabrication, and tooling concept that optimizes product performance and manufacturing needs, while giving early warning to any potential process problem.

## Benefits

The application of the methodology developed under this program will allow the design and manufacturing community to quantify the manufacturability of proposed designs. By quantifying assembly level variability, this methodology increased the focus on manufacturability during product design. The application of the developed methodology is pertinent to new aircraft design and the resolution of manufacturing problems in existing aircraft assembly lines. Knowledge of process performance during product definition permits identification of key part characteristics.

Additional benefits include:

- Improved interchangeability.
- Reduced fabrication and inspection cost.
- Production risks reduced during product design.
- Identification of necessary process improvement during product design.
- High first-time yields.

## Status

*Complete*
*Start date: September 1993*
*End date: December 1996*

## Resources

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# Process & Prototype Tool for Re-Engineering Test Requirements

**Contract Number: F33615-97-C-5132 ALOG Number: 1541**

## Statement of Need

Current state-of-the-art methodologies and techniques for creating manufacturing information and simulation models needed to drive the reengineering of "bad actor" electronics or to perform electronics systems upgrades are based upon manual and error prone approaches. In many cases, the design data representing the physical implementations is inaccurate and/or incomplete. The purpose of this effort is to explore and exploit emerging VHDL (VHSIC Hardware Description language) and VHDL-A (AHSIC Hardware Description Language - Analog) modeling practices and approaches. In addition, new principles and practices must be developed for automating the extraction of information needed to drive simulation model creation from legacy engineering and manufacturing information. Examples of legacy engineering and manufacturing information sources are test program sets, schematics, performance specifications and netlists.

The objective of this Phase I Small Business Innovation Research (SBIR) project is to develop tools and processes to develop form fit function and interface (F3I) specifications and simulation models for legacy electronics. This will ease the time and cost associated with reverse engineering of obsolete electronics.

## Approach

The contractor will develop a tool and process to capture test requirements from legacy data for electronics subsystems. The tool will be able to automatically generate test bench simulation models to ensure F3I compatible reverse engineering efforts.

## Benefits

Commercial industries will be able to use past designs for new electronic product endeavors. With time-to-market and cost issues critical for global competitiveness, the methodologies, techniques and tools developed during this effort will be applicable to design reuse for many commercial applications.

## Status

*Complete*
*Start date: May 1997*
*End date: November 1997*

## Resources

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# Process Web: Process-Enable Planning & Composition of an Agile Virtual Corporation

**Contract Number: F33615-96-C-5604 ALOG Number: 1473**

## Statement of Need

There is a need to rapidly configure a virtual enterprise (VE) from known, certifiable process capabilities from different team members that collectively offer the best alternative. This capability is critical to the formation of VEs, which are typically beleaguered with operating problems resulting from poor integration and mismatches between component processes of the different team members.

## Approach

This effort is concerned with the development of a unique process-enabled methodology and prototype software for composing, analyzing, and debugging VE designs. A "proof-of-concept" of the overall approach will be demonstrated and evaluated within the context of a real world problem context (e.g., Multichip Module Design at Hughes Aircraft Company). The Multichip Module (MCM) is an important product in the sense that it has applications ranging from workstations to missile seekers. The MCM design process cuts across multiple disciplines and core competencies making it well suited as the initial target application. The evaluation will consist of comparing the Process-Web technology to the traditional approach.

This program will develop and demonstrate an open, scalable modeling and simulation-based methodology and software for capturing virtual enterprise composing process models. At the heart of the overall VE integration approach are three new process engineering concepts: process composition, process substitution, and process mismatch analysis. The analysis methodology and software will: (1) simplify and accelerate the VE formation process and (2) produce an integrated product development process model which will serve as a guide to VE formation and operation in the real world.

## Benefits

First, this approach will dramatically improve the formation and integration of a virtual enterprise, by allowing users to: (1) explore the impact of several VE formation/outsourcing options and (2) uncover and eliminate the serious mismatches between customer and supplier processes. Second, the resultant VE process model will serve as a guide during VE process management. Third, the manager-oriented user interface will allow users to rapidly learn and apply the tool.

## Status

*Active*
*Start date: December 1995*
*End date: April 1998*

## Resources

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# Reasoning in 3-Dimensions: A Common Framework for Design, Manufacturing and Tactical Planning

**Contract Number: F33615-95-C-5560 ALOG Number: 1382**

## Statement of Need

Engineers shy away from innovative designs since they feel pressured to 'get things right the first time'. Therefore, many attractive ideas or radically new concepts remain unexplored. A range of new tools and methods is required to reduce designer's risk in the realization of yet unproved design alternatives. The designer's imagination of complex geometric interactions (3D reasoning ) is frequently the bottleneck in the evaluation of feasible design solutions. Even if a feasible design solution is found, its realization may be prohibitive from a manufacturing perspective. In response to these problems the present program on '3D Reasoning' is developing tools to:

- automatically generate process plans to manufacture parts with the help of layered manufacturing (LM) techniques,
- provide a 'clean interface' between CAD and CAM through spatial decomposition of CAD models, and to
- facilitate manufacturability evaluation of complex CAD geometries.

The LM planning efforts are focused on Shape Deposition Manufacturing (SDM) a novel process which combines additive and subtractive material processes. Innovative structures such as multimaterial parts, integrated assemblies or meso scopic devices can be fabricated with SDM. Such structures open the design space to create products of potentially unparalleled mechanical performance such as increased power density, and/or improved heat transfer from heat sources inside a component to the outside surface, both crucial features in many DoD weapon systems.

## Approach

- Develop algorithms and software to automatically translate CAD models into manufacturing instructions for SDM process steps in compliance with STEP, AP203.
- Demonstrate software by generating process plans for DoD relevant parts (gimbals for missile seeker).
- Develop algorithms and software to reduce 3D CAD models to 2.5D geometries.
- Demonstrate software through automatic shell mesh generation for manufacturability analysis.

## Benefits

- Layered Manufacturing planning software enables economic fabrication of one of a kind parts. A 'clean interface' between CAD and manufacture facilitates electronic bidding and ordering.
- Internet access to geographically distributed manufacturing sites offers improved part acquisition of DoD weapon systems.
- Adoption of STEP interface standard facilitates linking to a spectrum of CAD suppliers.
- Software for dimensional reduction of 3D models will enable automatic invocation of certain manufacturability analysis such as mold filling and stamping.
- Automated manufacturability analysis reduces risks with respect to downstream failures and unexpected costs.

## Status

*Active*
*Start date: September 1995*
*End date: September 1998*

## Resources

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# Responsible Agents for Product/Process Integrated Development

**Contract Number: F33615-96-C-5511 ALOG Number: 1447**

## Statement of Need

A designer seeks to embed a set of functions (e.g., optical, electromechanical, control) in an artifact with specified characteristics (e.g., weight, color, complexity, materials, power consumption, physical size). The functional view drives most designs, since it distinguishes the disciplines in which engineers are trained and in support of which design tools are available. Conflicts arise when different teams disagree on the relation between the characteristics of their own functional pieces and the characteristics of the entire product. Some conflicts are within the design team.

Responsible Agents for Product-Process Interactive Design (RAPPID) is a community of agents (active software objects with varying degrees of intelligence) that help human designers manage product characteristics across different functions and stages in the product life cycle. Agents represent not only design tools and humans with a stake in the design (including designers, manufacturing engineers, and marketing and support staff), but also the components of the design itself, and the characteristic of each component. These agents trade with one another for design constraints, requirements, and manufacturing alternatives, and the resulting marketplace provides a self-organizing dynamic that yields more rational designs faster than conventional techniques.

## Approach

The contractor:

• Identified relevant design characteristics, design process information design data flows, and characteristics for buy-and-sell prices, and provided a KIF/KQML compatible shared data repository for this information.

• Identified and implemented corresponding software information agents.

• Selected an appropriate object-based development environment.

• Developed a suitable client-server environment periodically throughout its development.

• Transitioned RAPPID technologies to other Manufacturing Automation and Design Engineering (MADE) contractors.

The second version RAPPID software was released in June 1997. This software includes a complete JAVA client to serve as the interface to the human agent for collecting market bid data and presenting the market data in tabular and graphical formats. Training is ongoing with Army TACOM engineers. TACOM is providing the Future Infantry Vehicle as a design testbed for the RAPPID system.

## Benefits

The RAPPID environment enhances a design team's ability to more thoroughly explore a product's design space, thus allowing for better optimized designs and shorter design cycle times.

## Status

*Complete*
*Start date: March 1996*
*End date: September 1997*

## Resources

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# Robust Design Computational System

**Cooperative Agreement Number: F33615-96-2-5618 ALOG Number: 1477**

## Statement of Need

The deterministic analysis used in the current design environment provides no quantitative values of risk, reliability, or projected failure rates. Quantifying risk requires numerically accounting for variabilities and uncertainties which is not currently done. Typical design practices employ a deterministic analysis of a particular design point using some combination of typical and worst case design parameters. Fabrication process variations are frequently ignored or again approached by evaluating a projected "worst case." In current practice, risk is typically quoted as a "factor of safety" using some "worst case" scenario. Sensitivity of the risk to the variabilities is generally unknown except for a few chosen parameters. Reliability numbers are based on historical experience, but generally the only reliability recognized is that derived empirically from expensive development testing. The current unavailability of the computation infrastructure and tools coupled with the lack of quantitative linkages between design and production prevent assembling a seamless numerical multidisciplinary system model. This results in only certain aspects of the design being examined in detail within a single disciple while the importance of variables at the system level are likely to be unknown. Thus, the system level interactions of the components are discovered in the test phase of the program when problems are very costly to correct. The objective of this effort is to develop and demonstrate engineering tools and information integration capabilities that could be used to evaluate more design alternatives than is possible today.

## Approach

The approach will build infrastructure and software tools for a robust design computational system (RDCS). It will also provide the Integrated Product and Process Development (IPPD) team improved ability to: a) explore, generate, store, and analyze design alternatives, b) numerically account for the effects of "downstream" variability's, c) quantify risk, reliability, and sensitivities using probabilistic analysis methodologies, and d) optimize designs for selected performance parameters such as costs, weight, or life.

## Benefits

The RDCS will develop tools and infrastructure to support the design engineer in rapidly exploring, generating, tracking, storing, and analyzing design alternatives. The design engineer will be able to begin with a parametric design representation, assemble a series of functional modules from multiple disciplines to simulate product and processes, efficiently evaluate the design options using distributed and parallel processing, invoke a variety of design sensitivity and optimization options, and effectively analyze the results to enable an informed design decision.

## Status

*Active*
*Start date: June 1996*
*End date: October 1999*

## Resources

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# Simulation Assessment Validation Environments

**Contract Number: F33615-95-C-5538 ALOG Number: 1336**

## Statement of Need

Military aircraft manufacturing does not enjoy the traditional cost benefits of mass production because large quantities are not usually required. Separating low cost from high volume requires new approaches to product and process design and technology maturation. Virtual Manufacturing (VM) supports this concept by applying modeling and simulation technology to prove out and select optimal new concepts.

The "Simulation Assessment Validation Environments" (SAVE) program is a first step in realizing the near-term objectives common to VM and the Joint Strike Fighter (JSF) program. The objective of SAVE is to implement, demonstrate, and validate integrated modeling and simulation tools and methods used to assess the impacts of product/process decisions on the affordability of advanced strike warfare technology.

## Approach

The effort is focused on initial implementations of VM strategically applied to specific real fighter and/or attack aircraft design and production affordability problems. The SAVE program consists of two phases. The goal of the Phase I demonstration is to take the user through a complete manufacturing scenario and communicate the functional capabilities of the developed tools. The Phase I demonstration will validate the core VM capabilities, identify performance and business metrics against real production problems, and point to areas for continued refinement/enhancement to be accomplished during the second phase of the program. The Phase II effort targets ongoing weapon system mechanical component or subassembly applications. Phase II culminates with a full demonstration of the developed VM capabilities applied to the targeted weapon system application.

Phase I was completed with live demonstrations of the SAVE architecture and toolset. Currently, an enhanced SAVE architecture for Phase II is being developed, which will expand the RASSP infrastructure used for Phase I. Tool wrappers will be developed using the CORBA standard. Investigation of potential scenarios for the SAVE Interim demonstration lead to the selection of the F-22 mid fuselage gun port area. This area is being redesigned to resolve a problem of the muzzle blast affection local structure. While performance of the structure is a key consideration, the design change must remain affordable.

## Benefits

- Affordability — Increased reliability of cost and process capability information.
- Quality — More producible designs with higher quality work instructions and fewer engineering changes.
- Producibility — Trouble-free, high-quality, first article production, involving no rework and fully meeting customer requirements.
- Flexibility — Rapid product changeovers, ability to mix production of different products, and quick return to producing previously shelved products.
- Shorter Cycle Times — Direct production without false starts.
- Responsiveness — Quicker response to customer's questions.
- Customer Relations — Improved relations through increased customer participation in the IPPD process.

## Status

*Active*
*Start date: April 1995*
*End date: December 1999*

## Resources

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*JDMTP Subpanel:*
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# Smart Valley CommerceNet

**Cooperative Agreement Number: F33615-94-2-4413 ALOG Number: 1210**

## Statement of Need

An outgrowth of a government research project, the Internet was originally used by colleges, universities and the government for research and development purposes. Until now, the Internet has been a difficult place to do serious business. Some of the reasons include: the lack of standard and easy-to-use interfaces; the lack of secure means of transmitting sensitive data or identifying users; and the lack of indexing and search mechanisms that make it easy for users to find information. CommerceNet was a consortium of Northern California technology-oriented companies and organizations whose goal was to create an electronic marketplace where companies transact business spontaneously over the Internet. CommerceNet stimulated the growth of a communications infrastructure that is easy-to-use, oriented for commercial use, and ready to expand rapidly. The net results for business in this region are lower operating costs and a faster dissemination of technological advancements and their practical applications.

## Approach

The CommerceNet marketplace supports all business services that normally depend on paper-based transactions. Buyers browse multimedia catalogs, solicit bids, and place orders. Sellers respond to bids, schedule production, and coordinate deliveries. A wide array of value-added information services have sprung up to bring buyers and sellers together. These services include specialized directories, broker and referral services, vendor certification and credit reporting, network notaries and repositories, and financial and transportation services.

## Benefits

CommerceNet eliminates data and transmission security issues, because there are no remote logins and passwords are not exchanged in the clear. In addition, authentication, authorization, and data encryption applications made available on CommerceNet lets buyers and sellers safely exchange sensitive information such as credit card numbers and bid amounts, sign legally enforceable contracts, maintain audit trails, and make or receive network payments through cooperating financial institutions. CommerceNet provides access to an on-line global marketplace with millions of customers and thousands of products and services, improving productivity and competitiveness. For information technology providers, CommerceNet is an opportunity to build Northern California's information infrastructure, to influence the development of Internet technology and standards for electronics commerce, and to participate in joint marketing efforts.

## Status

*Complete*
*Start date: April 1994*
*End date: April 1997*

## Resources

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# Spare Part Production & Reprocurement Support System

**Contract Number: F33615-90-C-5002 ALOG Number: 101**

## Statement of Need

Procurement of spare parts is expensive. A large portion of the cost for spare parts is attributed to the manufacturing data content. Manufacturing data content is driven by the need for human understanding and effective use of paper engineering drawings, which list the multitude of parts lists and military specifications. Paper drawings have historically been difficult to keep current and read. They are inaccurate because of part changes not incorporated into the drawings. Interpretation of the essential Mil-Specs with the drawings is a time- consuming and expensive task. The manufacturing operations within Air Force Materiel Command (AFMC) rarely use digital product data. When digital product data is generated, no process exists for the retention and management of that data. A need existed to have efficient two-way communication of product data between the Air Logistics Centers' (ALC) data repository and the manufacturing facilities. Also, manufacturing-specific data needed to be stored and cross-referenced for ease of use and reuse.

The objective of this program was to improve Air Force acquisition of spare parts through the use of digital technical data packages for reprocurement and internal manufacture. This program supports AFMC in the management of original component or subsystem product-definition data in digital format obtained during the acquisition phase of new weapon systems. It supports the preparation of technical data packages for competitive bidding or for internal manufacture of weapon system subsystems and components at ALCs.

## Approach

The SPARES System supports digital models and application software to define the spare-parts procurement package. A representative set of high-cost items, which are frequently procured, was selected to analyze the procurement process. The contractor then looked for ways that digital product models could be created. They designed the digital product models and used the prototype software to demonstrate the system concepts. User participation, guidance, and acceptance has been an integral part of this effort.

## Benefits

This project resulted in effective and accurate data and drawing interpretation through the use of computer support. For newly designed or redesigned parts, drawings are not necessary. Vendors, who supply the re-procured parts, have an easier, quicker, and more accurate understanding of the manufacturing requirements for the part being procured. The ALCs see a drastic reduction in work-order time through major reductions in processing times associated with data input, numerical control programming, and fixture/tool design. Approximately $2.5 million per year is being saved via reduced queue times in one manufacturing and repair shop. The final result is a more accurate parts definition conveyed to the manufacturer (internal or external) resulting in quality improvement, readiness enhancement, and extensive cost savings to the government through the reduction of excessive engineering and manufacturing preparation time.

## Status

*Complete*
*Start date: December 1990*
*End date: April 1997*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*General Atomics Corp*

*JDMTP Subpanel:*
*Manufacturing and*
*Engineering Systems*

# Strategic Planning and Operating Tools for Agile Enterprises

**Contract Number: F33615-95-C-5514 ALOG Number: 1363**

## Statement of Need

New budgetary pressures have emerged that will require the defense industry to respond rapidly to changing threats with low volume weapon systems at lower cost. The old structure of vertically integrated, hierarchically controlled, monolithic organization was very efficient for repetitive manufacture of many identical products. For today's defense requirements a new structure, the vertical enterprise has emerged. It brings together the resources of several companies and institutions to achieve a specific goal. The virtual enterprise may be a very large or it may be a partnership of few companies directed to a specific, niche product for which no one partner has sufficient resources to develop or produce. It may encompass a group of suppliers, manufacturers, and customers. In each case, there is a sense the virtual enterprise is transitory and that there will come a time when it no longer serves a purpose.

The objective of this program was to develop and test a family of strategic planning and operating tools for the formation, operation, and dissolution of virtual enterprises.

## Approach

The objective of this program was to develop and test a family of strategic planning and operating tools for the formation, operation, and dissolution of virtual enterprises.

The tools focused on three critical areas:

- Quality - This section addressed issues relating to the communication and demonstration of quality to the customer and the responsibility for Liability and Warranty that each member has.
- Intellectual Property - This section addressed legal issues such as Patent, Trade Secret, Copyright, and Trademark issues that relate to the protection of intellectual property for use by the venture and right to intellectual property developed by the venture.
- Allocation of Revenue - This section addressed financial issues such as determining risk reward sharing rules, allocation of profits, allocation of overhead costs, cost estimation for new products, and formulas for motivating cost reductions.

The tools were published as the "Handbook for Virtual Organizations: Tools for Managing Quality, Intellectual Property, and Sharing Risk and Revenues" (WL-TR-97-8013, Vol II). The report can also be purchased commercially in CD ROM format from Competitive Technologies, Inc. Additionally, the handbook was reviewed in light of the Federal Acquisition Regulations (FAR) and Defense Federal Acquisition Regulations (DFAR) to determine any constraints they might impose (WL-TR-97-8014, Vol III).

## Benefits

- Provided a set of tools that assist in the formation of virtual enterprises.
- Resulted in less time required to form contractor/subcontractor relationships.
- Teams of small suppliers are able to compete for large defense orders.
- Created a more robust industrial base for defense.
- Removed key legal and financial barriers to collaborative engineering.
- Resulted in higher quality with less oversight.

## Status

*Complete*
*Start date: January 1995*
*End date: October 1996*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Lehigh University*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Supply Chain Integrated Product/Process Development Pilot Project (SCIP)

**Cooperative Agreement Number: F33615-96-2-5602 ALOG Number: 1472**

## Statement of Need

It has long been recognized that there are large costs and substantial delays incurred by suppliers (ultimately passed along to their customers) due to inefficiencies in the movement of product information in the supply chain. Some of these costs are incurred due to technical problems, such as the need to translate product data when it is exchanged between CAD systems. Other costs are incurred because of miscommunication and because business processes are misaligned among members of the chain.

## Approach

The pilot is addressing these problems by piloting solutions in real-life settings and developing a guide and business case for those solutions. This means that both new technologies and new business practices will be tried in real automotive supply chains as they develop real parts. For this to be successful, the technologies have to be commercially available and the business practices have to be tried and proven. The primary technology is the STandard for the Exchange of Product model data (STEP), the new product data exchange standard, formally known as ISO 10303. The business processes being addressed are those related to Integrated Product/Process Development (IPPD) which will enable the supply chains to take advantage of STEP, resulting in significant improvements in performance. The business process activities are being undertaken in five commercial automotive supply chains and two military tracked vehicle chains. The five major activities include: As-Is Assessment; Benchmarking; Pilot Planning; Pilot Implementation; and Evaluation and Dissemination.

## Benefits

- Improved and more cost effective IPPD across the entire supply chain
- Cost effective reuse of original CAD Data for:
  Engineering analysis (e.g., finite element analysis)
  Rapid prototyping (e.g., stereo lithography)
  Virtual prototyping (digital mockup)
  Tooling design (packaging and digital preassembly)
  CNC programming and cutter path verification
  Documentation (e.g., service manuals)
- Documented business case for the use of STEP technology
- Clear and well documented path to deployment

## Status

*Complete*
*Start date: December 1995*
*End date: October 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*Automotive Industry Action Group (AIAG)*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# System Designer Advisor Baseline Enhancement

**Cooperative Agreement Number: F33615-96-2-5612    ALOG Number: 1482**

## Statement of Need

The objective is to develop and demonstrate a capability to: address an order of magnitude more design alternatives relevant to development of electromechanical assemblies without extending design time; optimize design for several objectives such as quality, performance, cost, manufacturability, maintainability and reliability at the same time; and reduce prototype development cycle time.

## Approach

The approach is to: build upon on-going work by the contractor to develop a System Design Advisor and Design of Experiments tool; add a System Engineering Information System; interface to the IRFPA-related toolset currently being developed by the contractor; and, add a Systems Requirements Management Tool. The contractor's earlier MADE program, the AM3 program, and this program together will develop complementary tools with access to: expanded data, simulations, analysis tools, subassembly design tools, and applications.

A digital systems design record including the design, analysis, and manufacturing setup for multiple design alternatives will be maintained. Relationships will be maintained between these objects so that alternative configurations can be maintained. The design knowledge represented by the objects and their relationships will be integrated with the design process, which will be captured in an integrated workflow system. In addition, the various design and analysis tools will be integrated with the virtual database in which the data and processes are brought together.

## Benefits

A design environment for imaging infrared missile seekers that provides the designer instant access to the capabilities of the factories that manufacture the subcomponents required for a new system. The tools and methodology will reduce missile seeker design time by between 200 percent to 1000 percent, reduce prototype cost by 400 percent, and highly reduce the possibility that a new missile seeker design will place a missile program at significant risk.

## Status

*Active*
*Start date: June 1996*
*End date: August 1998*

## Resources

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*DARPA Funded*

*Texas Instruments Incorporated*

*JDMTP Subpanel: Manufacturing and Engineering Systems*

Manufacturing and Engineering Systems

M&E Systems

# Textile/Apparel Initiative (Flexible Manufacturing/Information Exchange in a Textile Enterprise)

**Contract Number: F33615-94-C-4430 ALOG Number: 1252**

## Statement of Need

The ability to quickly reconfigure the various operations in the apparel enterprise and to respond quickly in short-time frames is dependent on the availability of raw materials, the load level and priorities of work-in-process and quantity of finished goods. Therefore, there is a critical need to coordinate the operations of the various departments in the apparel enterprise -- raw materials receiving, spreading, cutting, sewing and finished goods shipping -- through timely access to the right information.

The primary objective of this effort was to extend the basic real-time data collection system (developed and tested in the distributed sewing sections of the apparel enterprise) to collect and use data from other parts of the enterprise, i.e., raw materials receiving through finished goods shipping.

## Approach

An AS-IS model of the existing processes was developed to gain an understanding of the interrelationships between the different operations (departments) in the apparel enterprise. This model was used in conjunction with the apparel manufacturing architecture (AMA) to identify necessary enhancements to the basic distributed real-time shop floor control system (RTSFC) and resulted in the TO-BE model. Using this model, the distributed RTSFC was modified and the system was implemented and tested.

## Benefits

The basic distributed real-time shop floor control system developed in the base project was enhanced and used to track product flow throughout the entire apparel enterprise -- raw materials receiving through shipping and with operations distributed over several locations -- to achieve quick response objectives and meet the goals of the Industrial Base Pilots.

## Status

*Complete*
*Start date: July 1994*
*End date: June 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*Georgia Institute of Technology*

*JDMTP Subpanel:*
*Manufacturing and Engineering Systems*

# Thoroughly Testing Known Good Die

**Contract Number: F33615-94-C-4401 ALOG Number: 1186**

## Statement of Need

One of the biggest barriers to cost-effective multi-chip modules (MCM) is "known-good" integrated circuit die. Most semiconductor manufacturers probe die at the wafer level to determine obvious rejects, but do not thoroughly test and speed sort them until after packaging and burn-in. For new products, as many as three-five percent of the die that pass wafer probe will ultimately fail final test and as many as 50 percent may sort into a lower performance bin. Furthermore, unpackaged die may be damaged or degraded during handling, storage, or assembly into modules. This makes MCM production extremely inefficient, since latent defects are not usually detected until after the module is completely assembled, when rework is difficult and expensive. The objective is to develop, evaluate, and make available technologies for delivering known-good die.

## Approach

Macrocells have been developed to perform at speed testing of die at the wafer and assembled MCM occurrences of die. Demonstrations are currently underway with die manufacturers using macrocells manufactured with the 0.25 micron process at National Semiconductor.

## Benefits

The major relevance of embedded at-speed test to DoD will be the ability to define test software during the design process that can be viable for the life of the equipment. DoD procures systems that are in the national defense inventory for decades. Over this period of time, the computers and test equipment needed to test, diagnose, and service the equipment, will become obsolete and unobtainable. Using embedded test, the test equipment is integrated into the device(s) to be tested and the software only needs to move data into and out of the equipment on standard buses. If the test applications are written for popular software environments, the problem of porting this software becomes relatively insignificant with respect to the problems of cost and viability that exist with today's approach to long term maintenance of DoD equipment.

## Status

*Active*
*Start date: December 1993*
*End date: February 1998*

## Resources

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*DARPA Funded*

*Contractor:*
*Tektronix Inc.*

*JDMTP Subpanel:*
*Manufacturing and*
*Engineering Systems*

# Virtual Test

**Contract Number: F33615-93-C-4308 ALOG Number: 221**

## Statement of Need

Currently, test development costs for complex electronics systems often exceed 40-50 percent of systems development costs. In addition, there is the problem of conveying test related information from design to test and across multiple team members of a system development. Industrial base analyses have pointed to the need for more effective electronics system test. The need for tester-independent test requirements and strategies has been identified as a piece of the solution for the high costs associated with initial test program generation and retargeting of test program sets during system life cycle support. The viability of the concept of tester-independent test requirements information capture, and test program set generation from this information, has been demonstrated on a limited scale by past Air Force Laboratory and Air Force Manufacturing Technology Special Studies efforts. The objective of this program is to develop and demonstrate the methodologies and tools necessary for the capture of tester-independent test requirements and the targeting of this information to test programs for multiple testers.

## Approach

This program will use a test requirements specification language. In addition, this program will develop tools for accepting this formatted information for the creation of test programs for multiple target testers. The test program creation environment will be a CAD framework and have a graphical user interface to facilitate ease of use and understanding. This program will also demonstrate the use of a test code reuse library to further increase the efficiency of subsequent test programs generated with this approach and methodology. This effort will be scoped at addressing the methodology and supporting tools necessary to support the printed circuit assembly (PCA) and line replaceable module (LRM) level of electronic integration. The results of prior government laboratory efforts, system development efforts, and commercial developments will be used to maximize the impact of this program and potential for commercialization of program developments.

## Benefits

The demonstration for this program will use the most advanced printed circuit assembly and line replaceable module designs, considered state-of-the-art at the time of the program, to ensure the methodology and tools are robust enough for 'real' world test program set development processes. The methodologies, formats, and tools developed will be transitioned during the effort into commercial products to provide for the most rapid technology transition of program accomplishments.

## Status

*Active*
*Start date: September 1993*
*End date: May 1998*

## Resources

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*Air Force Funded*

*Contractor:*
*Lockheed Martin*
*Federal Systems*

*JDMTP Subpanel:*
*Manufacturing and*
*Engineering Systems*

# Advanced Reconfigurable Machine for Flexible Fabrication

Metals

**Contract Number: F33615-95-C-5500 ALOG Number: 1352**

## Statement of Need

One of the common problems plaguing the manufacturing process is excessive vibration of the cutting tool. This vibration is influenced by several factors including tooling, part fixturing, and machine structural dynamics. This project will address the machine structural portion of the problem by offering a machine configuration that is anticipated to be six times as stiff as conventional orthogonal axis machine tools with a first mode resonant frequency in the range of 200 Hz. It will develop a 21st century machine tool, the enhanced Octahedral Hexapod, which provides revolutionary advances in flexible fabrication technology. The objectives of this effort are to: 1) develop a reconfigurable machine for flexible fabrication of critical military components; 2) demonstrate high throughput, high precision, low cost production of aerospace components; 3) transition technology to spacecraft and robotic vibration control and precision position; and 4) introduce advanced materials technology into the U.S. machine tool industry.

## Approach

The technical approach for this project is based on state-of-the-art analytical models for structural dynamics, tool-workpiece interaction, and control simulation to enhance accuracy by minimizing vibration and machine distortion.

These models drive the incorporation of:

- Applying active vibration cancellation devices.
- Reducing the mass and increasing the stiffness of machining arms, spindles, and structural components.
- Exploiting near-zero coefficient of thermal expansion composites.

Metals

## Benefits

The benefits include:

- A machine tool capability of $\pm$ 2 μm accuracy, $\pm$ 1 μm repeatability, and a 75 percent increase in metal removal rate.
- Ability to machine small or large lots of critical components with equal precision, flexibility, and cost.

## Status

*Active*
*Start date: April 1995*
*End date: March 1998*

## Resources

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*Contractor:*
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*JDMTP Subpanel:*
*Metals*

# Advanced Six-Degree-of-Freedom Laser Measurement System

**Contract Number: F33615-96-C-5106 ALOG Number: 1449**

## Statement of Need

In order to remain competitive in today's global marketplace, U.S. manufacturers are constantly striving to hold tighter and tighter tolerances on the parts they produce. What this means is that the manufacturer needs to better control the machines that they use to produce these parts, and in order to do that they need an instrument that can quickly and easily characterize the geometric properties of the machines being used.

The objective of this Phase II Small Business Innovation Research (SBIR) program is the continuation of the Phase I technical effort. The contractor will design, build and demonstrate a prototype six-degree-of-freedom laser measurement system. The system is intended to measure geometric errors in the X, Y, and Z axis and pitch, yaw, and roll rotations of machine tools and coordinate measuring machines (CMM).

## Approach

The approach will be to build and test an improved roll detector based on lessons learned from the Phase I effort. The operability and stability of the final design will be determined and confirmed. The contractor will fully integrate the roll detector into an existing five-degree-of-freedom laser measurement system as a pre-production unit. Testing of the pre-production unit will be made to confirm adequacy of performance and evaluate short and long term stability.

## Benefits

The multiple degree of freedom measurement system has the potential for application in any industry area that uses a CMM - virtually every manufacturer in the world. This product could be a valuable tool for teaching factories and manufacturing extension centers as well.



## Status

*Active*
*Start date: July 1996*
*End date: July 1998*

## Resources

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*SBIR Funded*

*Contractor:*
*Automated Precision Inc.*

*JDMTP Subpanel:*
*Metals*

# Cell for Integrated Manufacturing Protocols, Architectures, and Logistics

**Contract Number: F33615-90-C-5003 ALOG Number: 89**

## Statement of Need

There is an ever-increasing need to educate and train industry, particularly small manufacturers, and academia in emerging technologies for advanced manufacturing.

The objective of this project is to establish an integrated flexible manufacturing cell for use as a laboratory for students, faculty, and small aerospace manufacturers. It was employed as a demonstration site for networking and other technologies. Demonstrations were primarily aimed at subcontractors.

## Approach

This program established a test bed to demonstrate technology involved in a small computer integrated workcell. Robots, machine tools, and computers were networked using Manufacturing Automation Protocol or other protocols. Shop floor control, MRP II and other software were integrated into the cell. Manufacturing engineering students and small aerospace subcontractors became acquainted with the new computer integrated manufacturing technologies associated with the cell.

## Benefits

Implementation of the cell provided faculty and students with an invaluable educational tool, as well as provide a research vehicle. In addition, Air Force Research Laboratory's Manufacturing Technology Division and Materials Division Manufacturing Science Program benefited by using the cell as a test bed and demonstration site for protocols and other technologies that are fostered by the Air Force and the Department of Defense. Central State University intends to demonstrate technologies to aerospace subcontractors. This capability will be a positive addition to the resources available in the Dayton area.

Metals

## Status

*Complete*
*Start date: July 1990*
*End date: September 1997*

## Resources

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*Air Force Funded*

*Contractor:*
*Central State University*

*JDMTP Subpanel:*
*Metals*

# Development of a New Precision Magnetic Spindle Technology

**Contract Number: SPO900-94-C-0007 ALOG Number: 1229**

## Statement of Need

At present most machine tool spindles are supported on ball bearings. The vibrations in the rolling motion mechanism limit their precision to about 50 micro inches. To achieve higher precision, air bearing spindles are often used, but their precision is restricted by the air pumping-induced vibrations. Alternative spindles, supported on active-magnetic-bearings are prohibitively expensive because they employ complex control equipment. In order to achieve ultra-high precision at lower cost, advances in spindle technology are required. The passive bearings of magnet disks offer very high precision up to 0.05 to .8 micro inches. The basic concept is to employ passive magnetic bearings to support the spindle without contact. It is intended to support the spindle on two passive bearings and drive it by a motor. This magnetic spindle concept retains the non-contacting advantage of magnetic bearings but without the added cost of complex control equipment.



## Approach

The principal aim of this project was to produce an ultra-high precision magnetic spindle. This was accomplished by fabricating three classes of magnetic spindle prototypes - called the concept spindle, the high precision spindle, and the ultra-high precision spindle. Each prototype spindle improves the precision by applying the knowledge gained in testing the predecessor class spindle. The ultra-high precision spindle is the end-product of this project, offering the highest precision, on the order of sub-micro inches. This was a phased program to develop this new magnetic spindle. Phase I - A one-year demonstration phase in which a proof-of-concept magnetic spindle was built to establish the viability of passive bearings to support the precision spindles. Phase II - A one-year ultra-high precision spindle development phase in which five spindles were built and tested in the field. Other implementation opportunities include: turbo molecular pumps, flywheels, momentum wheels, canned pumps, machine tool spindles, and domestic refrigeration pumps.

## Benefits

This magnetic spindle development project produced a high-precision, low- cost spindle which has considerable impact on the machine tool industry. Conventional spindles require complicated support equipment for lubrication. However, since the magnetic spindle runs without contact, it does not require lubrication equipment or bearing cooling equipment, saving significant costs in maintenance and ensuring long life. The simplicity of the magnetic spindle concept made it possible to achieve several important technological goals, including higher precision at lower cost. The technology development of this effort will be applicable to future Department of Defense development. This technology can be transitioned into applications such as high precision cutting, high speed milling and spray painting for military aircraft, ships, etc.

## Status

*Complete*
*Start date: June 1994*
*End date: May 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*Precision Magnetic Bearing Systems*

*JDMTP Subpanel:*
*Metals*

# Engine Supplier Base Initiative

**Cooperative Agreement Number: F33615-95-2-5555 ALOG Number: 1265**

## Statement of Need

Until recently, the industry's technological base was sustained and dominated by the drive to maintain the United States' military edge. With reduced defense spending in the United States, engine designers, material developers, and manufacturing engineers must confront a new challenge. In the past, performance at any cost was the military rule. However, the future of the gas turbine engine industry will be based not only on performance, but affordability as well. A need exists to establish a national initiative to address the affordability of gas turbine engines by attacking the high cost areas known to exist. This program is aimed at providing more affordable propulsion by identifying and attacking high cost manufacturing processes and business practices within the military engine supplier base community.

## Approach

This effort addresses the affordability of gas turbine engines by effectively coupling advanced technology tools, new business practices and policies, and lean principles. The majority of the manufacturing related to this particular sector is conducted at the supplier base. This effort is being lead by the investment casting supplier base community with the engine manufacturers as team members defining the requirements. The focus of this initiative is on investment casting of complex nickel-base superalloy and titanium-base airfoil and large structural castings for man-rated gas turbine engines. Emphasis is on reducing lead times for prototype and production castings, significant reduction in rework of structural castings, reduction in scrappage rates of airfoils, and elimination of redundant specifications. Metrics are measured through major component demonstrations for military engines. The effort is structured to consist of three phases. Phase I, Concept Phase, consists of qualitative benchmarking of the "as-is" process, and identification of key tasks for "proof of concept" demonstration and validation. The Concept Phase includes an implementation/transition plan to ensure low risk entry of the technology and tools into production. Phase II, Demonstration and Validation Phase, demonstrates and validates the tools and practices identified in the Concept Phase. Phase III, Production Transition Phase, incorporates successful technologies into a production run and measures the improvements against the baseline.



## Benefits

This effort will enable the United States to maintain its technological superiority in the gas turbine engine business while providing for affordable propulsion for future systems. The goals of the program are: to achieve a 50 percent improvement in quality as related to structural rework, airfoil tolerance, and single crystal scrap; to achieve a 25-50 percent improvement in cycle as related to production cycle time, tooling procurement, and new part design and process development time; and to build stable and cooperative relationships internally and externally, to implement cultural change in an interorganizational environment.

## Status

*Active*
*Start date: September 1995*
*End date: August 2001*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*Howmet Corporation*

*JDMTP Subpanel:*
*Metals*

# Flexible Fabrication with Superconducting Magnetic Clamps

**Cooperative Agreement Number: F33615-95-2-5540 ALOG Number: 1379**

## Statement of Need

Existing hard tooling methods are extremely expensive and time consuming to produce, and will not meet the needs of many future military and commercial products. These needs include dramatically lower unit costs and shorter lead times. Tooling is a major component of unit cost, especially when production quantities are reduced as is occurring with defense acquisitions. Lead times are also becoming more important with the increased use of prototype programs and fly-off competitions.

The general solution to the problem of hard tooling cost and lead times is the development of flexible tooling hardware and techniques. One proposed solution for a practical flexible tooling system is to apply high-temperature superconductor fabrication to make a powerful, but controllable, magnetic clamp. These superconducting magnets have very high clamping forces, are durable, can survive autoclave environments, and unlike permanent magnets, can be easily turned off and on.

The key objective of this project is to develop and promote the commercialization of new flexible tooling systems that extend the state-of-the-art of current tooling capabilities, and through their use, significantly reduce nonrecurring tooling costs. The overall goal is to design, build and demonstrate a flexible manufacturing tooling system for composite and metal fabrication and trim.



## Approach

The approach will be in four steps:

- Establish the cost and performance requirements for a flexible tool and its components. To do this, the contractor will examine the cost and capabilities of existing tooling. Analyses based on these data will be key inputs to the design task to ensure that the technology developed is affordable.
- Design, fabricate, and test the components of the flexible tooling system. The superconducting clamp is a new and enabling technology which has not previously been reduced to practice or integrated into a practical tooling system.
- Verify flexible tool performance by building and demonstrating a manufacturing ready prototype.
- Perform a manufacturing cost analysis of the flexible tool. In addition, an industrial engineering analysis will be performed for implementation of the flexible tool in full scale production of the demonstrated part.

A key feature of this approach is the use of an Integrated Product Development (IPD) team which includes members of the user group to ensure linkage between user needs and engineering results.

This program was proposed as a three-phase effort, with Phase I as a feasibility demonstration, Phase II scale-up, and Phase III as full scale demonstration. This program will be completed through Phase I. Phases II and III have been cancelled by DARPA.

## Benefits

- Hard tooling cost reduced up to 65 percent.
- Tool design and fabrication time reduced by 80 percent.
- Setup time reduced up to 80 percent.
- Machine utilization increased over 200 percent.
- Future capital expenditures reduced since tools are reused.

## Status

*Active*
*Start date: August 1995*
*End date: December 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*Boeing Company*

*JDMTP Subpanel:*
*Metals*

# Flexible Laser Automated Intelligent Research System for Manufacturing and Fabrication



**Contract Number: F33615-95-C-5503 ALOG Number: 1354**

## Statement of Need

Reconfigurable tooling for metal forming and shaping, precision cutting, grinding, drilling, welding, and surface treatment of composites, superalloys, refractory alloys, and titanium alloys for fabrication of propulsion and platform systems are desired. Department of Defense and commercial systems are becoming more dependent upon high precision machined parts to maintain technological and performance superiority. The ability to provide affordable, precision components in small lots is beyond the capability of today's machine tools. Flexible tooling for forming, shaping, precision machining and joining of advanced materials will create a new capability in industry to fabricate parts in small lots or in mass production in assembly line for affordable military and commercial systems. Improved speed, precision and consistency of the tooling system will provide the basis for affordable ultra fine precision components.

Improved global competitiveness in manufacturing, for U.S. industry using industrial laser technology and reconfigurable machines and tooling technology to its fullest potential, is a goal of the program.

## Approach

The Flexible Laser Automated Intelligent Research (FLAIR) System for Manufacturing and Fabrication will bring together several advanced technologies by providing the research and development to demonstrate advanced laser processing of materials. The program will develop laser-material interaction modeling for titanium and lead alloys to support industrial applications. Various laser processing methods will be explored for joining, forming, and surface treatment of titanium fabricated materials and for the weldability of lead alloys. The knowledge from this program will be applied to two industrial processes. The first application will be the repair and surface treatment of titanium turbine blades. The second application will be for production welding of lead-acid battery components.



## Benefits

This program focuses on technology development that will lead to major advances in the ability to repair turbine engine components and other aircraft parts that have been scrapped in the past. Development of this technology will provide significant benefits for defense and commercial aerospace products, while also offering application as a dual-use technology. The maturity of this technology will greatly affect the industry's ability to process and repair lead and titanium alloys. Potential users of this technology include, but are not limited to, the aerospace and automotive industries. The DoD weapon systems that will benefit from this technology include, at a minimum, all aircraft and engines with repairable titanium components.

## Status

*Active*
*Start date: April 1995*
*End date: December 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*American Welding Society*

*JDMTP Subpanel:*
*Metals*

# General Purpose Noise Cancellation Processor

**Contract Number: F33615-94-C-4403 ALOG Number: 612**

## Statement of Need

The cost and size of large control-computers have been the principal barriers to the use of active noise and vibration control (ANVC) in commercial applications. Current ANVC systems are computationally very complex, often requiring computer systems with more than one billion floating points of 32 bit processing with a computational latency of 10 microseconds or less. Since the cost of these computer systems is so high, ANVC systems have been used primarily in high-value military applications. The smaller and cheaper computer system developed under this project would meet the requirements of most ANVC systems. Such systems are now in use by the Navy to reduce ship-radiated and ship-interior noise. The Army is developing ANVC systems to quiet tanks and trucks, and increasing use of ANVC is expected to reduce helicopter noise and vibration.

The objective of this program was to create pervasive use of active noise and vibration control (ANVC) technology by inserting a general purpose noise cancellation system product into consumer products, both military and commercial.

## Approach

This was a two-year development effort that completed three demonstrations of prototype multi-chip module (MCM) products by General Motors Corp. Motorola will further develop the MCM product for commercial sales.

MCM technology was developed during the early 1990's at several companies, often with Defense Advance Research Projects Agency support. QuietChip is the first hybrid, 40 Mflop computer built as an MCM, and it should lead the way for a new generation of real time processors used as system controllers. It has a nine-layer substrate with a 13 integrated circuit die on one side and a number of surface mount parts on the other. Up to twelve MCMs can be paralleled on the same data bus to expand the ANVC system size. All design and manufacturing files were transferred electronically and the completed MCMs were debugged over the internet via modems. Six MCMs were used in parallel computing architecture to successfully demonstrate an ANVC system that reduced road and engine noise in an automobile supplied by General Motors.

The purpose of this project was to produce an active noise and vibration control electronics package that will accept the sensors and drive the actuators of at least half of all active noise and vibration control applications that had been identified, including the potentially largest ones. Specifically, the contractor targeted active noise and vibration control applications such as active isolation of machinery vibration, active reduction of vehicle cab noise, active reduction of engine intake and exhaust noise, active control of structural vibration, and automatic ride control of selected vehicles. The contractor reduced the size and cost of active noise and vibration control electronics by putting all electronics on an MCM. Low-computational latency was achieved by integrating the A/D chip on the MCM, using low-latency technology. In this way, the contractor achieved the requirement of low latencies.

## Benefits

This General Purpose Noise Cancellation Processor project provided general-purpose, fully adaptive, broadband/tonal, multi-input-multi-output controller capability that can be incorporated with the controller functionality and algorithms. The active noise and vibration control electronics in this program will minimize size and costs, thus demonstrating good potential for commercial markets which can directly impact the United States' competitiveness. This project will have direct impact on engine manufacturing and vibration control technology.

## Status

*Complete*
*Start date: December 1993*
*End date: January 1997*

## Resources

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*DARPA Funded*

*Contractor:*
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*JDMTP Subpanel:*
*Metals*

# Kansas Manufacturers, Inc. (formerly, Kansas Manufacturers Association)



**Cooperative Agreement Number: F33615-94-2-4419 ALOG Number: 1219**

## Statement of Need

The objective of this program was to demonstrate and document that a consortium such as the Kansas Manufacturing Association can provide support and structure to increase competitiveness and promote economic growth of small contract manufacturing firms while protecting their independent private ownership status. In addition, the objective of this program was to preserve the defense/aerospace capabilities of small contract manufacturing firms to serve major defense/aerospace manufacturers.

## Approach

The approach of this program was to; 1) provide support for defense/aerospace sub-tier contract manufacturers for transition to commercial contract, and eventually product manufacturer; 2) seek licenser opportunities for products not presently marketed or produced in the United States in order to expand member firms' production and opportunity for economic growth; 3) improve member firms' leadership and competency through management and employee education and training programs; 4) implement state-of-the-market technologies in member firms to equip them with communication and necessary production tools for improved dialogue with major manufacturers and suppliers in both the United States and internationally.

## Benefits

This program created and supports a network of small manufacturers to improve their competitiveness and assist them in transitioning from defense to commercial business. This program also provided a model for other organizations establishing similar networks. It demonstrated the feasibility and desirability of network arrangements among small manufacturers as an efficient and effective level of service by U.S. suppliers.

Metals

## Status

*Complete*
*Start date: March 1994*
*End date: March 1997*

## Resources

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*Contractor:*
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*JDMTP Subpanel:*
*Metals*

# Large Aircraft Robotic Paint Stripping

**Contract Number: F33615-91-C-5708 ALOG Number: 165**

## Statement of Need

Coatings for aircraft are formulated to provide environmental protection for external surfaces. These coatings must have sufficient durability to sustain protection between scheduled overhaul periods. Aircraft coatings are subjected to temperature extremes, abusive damage during unscheduled maintenance, and exposure to ultraviolet radiation. These tightly adherent and durable coatings must be completely removed during programmed depot maintenance because of paint deterioration, surface damage, coating build up, and the need for access to bare aircraft surfaces to facilitate nondestructive inspection. The inherent toughness and durability of these coatings makes stripping or removal difficult and expensive. The Air Logistics Centers currently remove coatings from aircraft with methylene chloride-based chemical stripping compounds followed by mechanical abrasion to remove any residuals. Chemical stripping has several disadvantages: slow process time; expensive chemicals; hazardous environment; premature degradation of the working areas; and special disposal techniques to remove chemicals.

The prime objective of this program is to establish for Oklahoma City Air Logistics Center (OC-ALC) an automated, low-cost paint removal capability for large aircraft with minimal environmental impact. The program will establish an automated stripping process with the following characteristics: reduced aircraft preparation, cleanup, and depaint man-hours; reduced depot flow time; reduced ALC personnel exposure to the extremely hazardous work environment; lower cost; and a significant reduction of toxic/hazardous waste produced.



## Approach

The LARPS program is an automated paint stripping system to replace manual chemical stripping operations. LARPS uses a low-cost, high-pressure water process which does not damage thin-skinned metallic aircraft surfaces.

Two additional contract changes have been accomplished after the start of this program. A joint initiative with the Navy demonstrating high-pressure water coatings removal for stripping ships and submarines in a dry-dock environment. The Navy waterjet system uses a completely different nozzle and overall system design than the Air Force's LARPS. The Navy system has demonstrated a 100 percent recover at the source with stripping rates from 175-225 square feet per hour, and as a result, additional Navy systems are being procured. The second contract change produced an Aircraft Component Subsystem (ACS). The ACS provides an automated high-pressure water coatings removal for smaller components (C-135 flaps) that are removed from the aircraft during stripping. The system is capable of stripping 40,000 square feet annually, demonstrating semiautomated, environmentally safe coating removal with no damage to the aircraft components and no hazards to personnel.

## Benefits

LARPS will reduce hazardous waste by 94 percent, eliminating 135,000 gallons of chemical stripper annually, and enabling Oklahoma City ALC to become more compliant with environmental directives and requirements. It will reduce man-hours by 50 percent and remove personnel from a hazardous work environment. The LARPS system will be qualified to strip C-135 aircraft, but future plans will extend its application to B-1 aircraft.

## Status

*Active*
*Start date: June 1991*
*End date: February 1998*

## Resources

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*JDMTP Subpanel:*
*Metals*

# Laser Forming for Flexible Fabrication

**Contract Number: F33615-95-C-5542 ALOG Number: 1369**

## Statement of Need

Reconfigurable tooling for metal forming, welding and surface treatment of composites, superalloys, refractory alloys, and titanium alloys for fabrication of propulsion and platform systems components is in high demand in today's industrial environment. Department of Defense and commercial systems are becoming increasingly dependent on high precision machined parts to maintain technological and performance superiority. The ability to provide affordable, precision components in small lots is beyond the capability of today's machine tools. Flexible tooling for forming, shaping, precision machining and joining of advanced materials will create a new capability in industry to fabricate parts in small lots or in mass production in assembly lines for affordable military and commercial systems. Improved speed, precision and consistency of the tooling system will provide the basis for affordable ultrafine precision components. The ultimate goal of this program is improved global competitiveness in manufacturing for U.S. industry that utilizes industrial laser technology, reconfigurable machines, and tooling technology to their full potential.

The objectives of this program are to demonstrate the feasibility to predictably laser form components without the use of heavy machinery and tooling.

## Approach

Specimen Definition will be accomplished by material selections based on the needs of the end users. The list of candidate materials includes: high-strength low-alloy steels, high temperature nickel and iron base alloys, titanium alloys, high conductivity alloys and high strength refractory materials. Predictive model development/validation will be done by developing improved models for laser forming that build on the existing models. The definition of the critical model features, process parameters, and material constants will be performed in an iterative process forming and evaluating one- and three-dimensional samples. Laser forming experiments will be performed using the Laser Articulated Robotics System. Sample evaluation will encompass the characterization of grain growth in the heat affected zone, development of any detrimental phases or precipitates in the base material, and the identification of any mechanical defects created by the forming process. Cost benefit analyses will be performed to show schedule and cost impact of laser forming versus conventional sheet metal fabrication.

## Benefits

The implementation of this technology eliminates the cost and development time for complex tooling and reduces the cost for producing small production lots or prototype hardware. Laser forming offers a viable alternative fabrication tool to expensive, long lead time, numerically controlled machining or conventional mechanical forming.

## Status

*Active*
*Start date: September 1995*
*End date: May 1998*

## Resources

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*JDMTP Subpanel:*
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Metals

# Lean Blade Repair Pilot

**Contract Number: F33615-93-C-4301 ALOG Number: 314**

## Statement of Need

Stringent mission requirements have resulted in engine manufacturers using advanced superalloys (e.g., directionally solidified (DS) and single crystal (SC) in novel airfoil configurations). These advanced alloys typically have limited weldability. The current repair techniques consist of rebuilding worn blades primarily through manual welding operations. Current manual repair methods do not have the repeatability to produce a cost-effective repair. A flexible, automated welding machine (FAWM) will meet the requirements to weld repair blades currently being repaired as well as projected future blade repair requirements.

The objective of this program is to establish advanced manufacturing technology for cost-effective semi-to-automatic repair processes for selected Air Force high performance gas-turbine engine components. These technologies will be installed at Oklahoma City Air Logistics Center (OC-ALC). This effort will involve selecting the most efficient and cost-effective process between laser and pulsed-arc welding technologies. These two processes have proven to provide excellent weld properties on a laboratory scale, but have not been used in production.

## Approach

The goal of this Air Force Manufacturing Technology program is to demonstrate advanced manufacturing concepts and technology to improve the quality and reduce the repair cycle time of Air Force high performance gas turbine engine components in the Blade Repair Facility at Oklahoma City Air Logistics Center.

The goal is the incorporation of three efforts. To provide process optimization design and analyses to the Propulsion Production Division in implementing advanced manufacturing concepts and practices in the improvement of the operation of the Blade Repair Facility. To construct a computer model of the jet engine overhaul and repair process. To develop, validate, and install an automatic tracking system for in-process turbine blades. The program shall draw upon the information developed by previous modeling as well as manufacturing practices and principles used in industry. Where possible, improvement actions will be implemented immediately but where necessary, improvement actions requiring the purchase, and/or installation of additional equipment will be implemented later. Throughout the program, success will be measured by improved cycle times, decreased inventory, and improved quality, resulting in improved customer responsiveness and elimination of wasted resources.

## Benefits

Benefits derived from this task include: reduced scrap by 30 percent; reduced cost of blade and blade-tip overhaul; and new capability to process thin-walled hardware. The task will include an option to design, fabricate, and install the FAWM for a variety of Navy blade and vane components at Cherry Point Naval Aviation Depot. Potential cost savings is about $24 million over two years. This only accounts for three engines; there are five in the program.

## Status

*Active*
*Start date: September 1993*
*End date: June 1998*

## Resources

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# Manufacturing Technology for Welded Titanium Aircraft Structures

**Contract Number: F33615-93-C-4302 ALOG Number: 713**



## Statement of Need

Tactical fighter aircraft require titanium structures to meet strength and temperature requirements. This class of structure represents up to 30 percent of an aircraft's structural weight. Conventional titanium aircraft structure is difficult and expensive to fabricate because of the extensive machining, hot forming, drilling, and fastening involved. The construction of titanium structural assemblies by welding can potentially be lighter and more economical with less material waste. Precision welding of titanium offers the ability to structurally join large titanium components without fasteners. Reduction in fasteners can result in a significant cost and weight savings and can also provide reliable, leak tight joints for fuel cells.

The objective of the Manufacturing Technology for Welded Titanium Aircraft Structures program was to develop, demonstrate, and validate new welding processes and associated manufacturing methods that significantly reduce the cost and risks associated with implementing and using these processes in the production of fighter aircraft, while still meeting performance, quality, supportability, reliability, and flexibility requirements. The F-22 aft fuselage forward boom was identified as the baseline design on which to focus process improvements. Using an Integrated Product Team (IPT) approach, cost and weight drivers were identified and the selection process focused on those drivers and identified technologies which had the highest implementation potential to reduce the cost and weight. The program consisted of three phases: Phase I, Requirements and Technology Assessment; Phase II, Process Development; and Phase III, Manufacturing Demonstration. Phase I: (1) defined a "baseline" for cost, weight, and risk comparison purposes; (2) developed alternative designs and processes; (3) identified cost and risk drivers; (4) conducted a state-of-the-art (SOTA) assessment; and (5) selected processes which offer the highest potential payoffs. Phase II developed preliminary designs, fabrication plans, manufacturing processes, and tooling concepts and validated them by building and testing subscale components. Phase III, consisted of producing a full-scale demonstration component using the selected, high-payoff improvements in designs, processes, and tooling to verify the concepts. Demonstration of the improvements on full size hardware was performed to facilitate implementation of the processes to production.



## Approach

The program developed, demonstrated, and implemented producibility improvements in the manufacturing processes required to affordably produce large complex, high quality welded titanium fighter airframe assemblies. The developed processes also improve structural reliability and reduce weight in the assembled structure. The cost drivers associated with the fabrication of the welded titanium structure of the F-22 aft fuselage forward booms were identified to be the ancillary processes associated with the welding process and not the electron beam welding process itself. Process improvements including: localized weld repair, localized stress relief, localized cleaning methods, laser weld finishing passes, automated inspection methods, witness line application tools, robotic weld bead shaving and revised electron beam welding schedules were developed to address each of the identified cost drivers. Each of the process improvements were demonstrated and validated on a two bay section of the forward boom to illustrate the production readiness and to facilitate the rapid implementation of the processes to the production floor. The localized weld repair, localized cleaning methods and witness line application tools have been incorporated into the processes being used to build the F-22 EMD vehicles. The other process improvements will be implemented during F-22 production in accordance with implementation plans.

## Benefits

It is estimated that implementation of all of the process improvements into the production of the F-22 would result in a cost avoidance exceeding $100 million, over the life of the program.

## Status

*Complete*
*Start date: August 1993*
*End date: January 1997*
*Final Report: WL-TR-96-8032*

## Resources

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*Contractor:*
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*JDMTP Subpanel:*
*Metals*

# Metal Forming Simulation

**Contract Number: F33615-93-C-5318 ALOG Number: 615**

## Statement of Need

Rubber pad forming (Guerin process) is one of the important methods of forming aluminum sheet parts to repair airframes at the Warner Robins Air Logistics Center (WR-ALC). The depot repair process requires a flexible sheet metal manufacturing capability to meet and exceed the customer's needs. Customer needs are usually high variety, low job order quantity (JOQ) orders. Typically, the time required to produce such orders is critical in maintaining the customer's war fighting capability. Successful sheet metal forming begins with the design and manufacturing of quality tooling. The forming of intricate aircraft parts with complex contours and bends can result in fracture and wrinkling defects. These defects can be eliminated through proper tool design. Until now, the design and manufacturing of complex form blocks was a trial and error process. Multiple prototype designs would be required to develop a tool that would completely eliminate forming defects. The design process required scrapping parts and required machine time that could have been used for production. This tool design process combined with the high variety and low JOQ customer requirements caused problems for WR-ALC sheet metal operations.

The purpose of this program was to establish a computer-aided design/computer-aided manufacturing/computer-aided engineering (CAD/CAM/CAE) system to simulate the Guerin sheet metal forming process. The simulated forming process would then be used to test CAD models of various dies, for part formability. The overall objective would be the reduction of tool concept to part production time, increased part quality through improved tool design, and an overall cost per part reduction. Variations of the Guerin process including hydroform, hydropress, and fluid cell (also known as the Verson-Wheelon) were also to be simulated.



## Approach

This task consisted of three phases. In Phase I, the contractor conducted a needs analysis and established system requirements for the WR-ALC system. This system is capable of being integrated into WR-ALC tool design and manufacturing operations. The system models the cold forming of aluminum and steel sheet metal components using the Guerin process. The system is capable of modeling components up to ten times larger than those found on any aircraft in the entire U.S. Air Force inventory.

In Phase II, the contractor developed a computerized analytical model. The contractor developed a material model which describes the formability of the workpiece material. A simplified model was developed for predicting important equipment set-up parameters.

In Phase III, the contractor validated the analytical model developed in Phase II with physical models. The physical models were used to determine the forming characteristics of those materials under various forming conditions. The physical models were representative of the analytical model simulations.

## Benefits

Benefits include increased throughput, reduced scrap, and potential cost savings estimated to be $500,000 per year when fully implemented. Also, technology will be transferred to other ALCs, resulting in additional cost savings.

## Status

*Active*
*Start date: July 1993*
*End date: December 1997*

## Resources

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*Metals*

# Metal Forming Tool Design

**Contract Number: F33615-96-C-5107 ALOG Number: 1460**

## Statement of Need

Tool design and tool fabrication are crucial steps in the manufacture of sheet metal parts. During the process of metal forming, the blank conforms to the configuration of the tool. Therefore, a faulty tool will produce an unacceptable part. At present, the remedy for this problem is the check/straightening or handworking of the part following the forming operation. This manual rework sometimes accounts for 40 percent of the total touch labor hours in aerospace industries. In addition, handworking inevitably leads to variability of the part which results in additional cost during sub-assembly or final assembly of the product. The majority of the metal fabricators still use the trial-and-error approach to produce tools. It is not uncommon to rework a tool five times for a complex forming operation like stretch forming. The challenge of this program is to resolve the problem of cost, quality, production cycle time, and prototyping time.

## Approach

This Small Business Innovation Research (SBIR) Phase II project is sponsored by the Director Defense Research & Engineering to transfer DoD developed technology into the private sector. The project is transferring technology from the Advanced Tooling Manufacture for Composite Structures (ATMCS) program into the metal forming domain. The objective is to design and implement an intuitive, easy to use, expandable, full function, brake forming, stretch forming, and hydroforming tool design software based on the original Manufacturing Technology Division ATMCS technology.

## Benefits

There is tremendous commercial potential for the proposed metal forming tool design software. The system would:

- produce accurate tooling which eliminates trial-and-error in tool fabrication
- produce affordable parts by elimination of handworking
- produce parts with minimum variability
- use a uniform tool design concept
- minimize process time

## Status

*Active*
*Start date: June 1996*
*End date: June 1998*

## Resources

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*JDMTP Subpanel:*
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# Mobile Automated Scanner (MAUS)

**Contract Number: F33615-91-C-5664 ALOG Number: 1508**

## Statement of Need

Nondestructive inspection of aging structures involves a difficult balance between accurate detection of potential defects, and cost-effective completion of inspection tasks within the time and budget constraints of an aircraft maintenance organization. It is often cost prohibitive to survey large sections of the aircraft for potential defects, therefore inspection techniques commonly used for aging aircraft evaluation are currently focused on small, specific areas of concern. Enhancements in nondestructive inspection technology have resulted in fast portable scanning capabilities that allow for improved flaw detection over large areas and reduced inspection costs. The Large Area Inspection of Disbonds (LARID) program addresses the rapid, nondestructive inspection of large bonded structures. This program extends the work previously completed under the Large Area Composite Inspection System (LACIS) program to enhance the Mobile Automated Scanner (MAUS III) nondestructive testing system with additional bond testing capabilities. Specific enhancements being considered are pitch-catch resonance, mechanical impedance analysis, eddysonic and automated tap testing. Additional program goals include improved operator ergonomics, enhanced system durability, and reduced inspection costs.

## Approach

- Baseline Mobile Automated Scanner (MAUS) unit with current Materials Division's MAUS design.
- Address production demonstration efforts required to insure unit portability, durability, maintainability, and affordability.
- Build a prototype production unit to support field implementation test validation.
- Document an implementation plan which considers training, operation and support.

## Benefits

This project will:

- Minimize the requirement to periodically disassemble major structural components to inspect for flaws, defects and damage.
- Significantly reduce cost and inspection time.
- Increase fleet operational readiness.
- Increase field level inspection capability.

## Status

*Complete*
*Start date: November 1996*
*End date: November 1997*

## Resources

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*Air Force Funded*

*Contractor:*
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*JDMTP Subpanel:*
*Metals*

# Moisture Detection in Honeycombs Via Advanced Radioscopy

**Contract Number: F33615-91-C-5623 ALOG Number: 1525**

## Statement of Need

The Air Force goal of obtaining higher performance, more durable aerospace structures and turbine engines mandates the pursuit of identification and development of advanced structural and high temperature materials. These material developments require corresponding developments in the area of material and component inspection of materials with complex internal structures. Even for the simpler metallic materials employed in current turbine engines, inspection techniques are essentially qualitative in nature and have been developed primarily to detect material flaws and not to characterize the internal structure of the inspected materials. The goal of this program is to develop and transition a portable high resolution real-time X-ray radiographic (HRRTR) imaging system capable of assessing physical and chemical properties of complex multi-phase materials.

## Approach

This program will consist of the design, construction, evaluation, and demonstration of a prototype advanced real-time radiographic imaging capability based on the development of a solid state X-ray detector. This program will be divided into three phases: 1) Core RTR system integration/evaluation and brassboard development; 2) Brassboard RTR system integration/evaluation and full scale prototype development; and 3) Full scale prototype system demonstration using full scale aerospace airframe structural materials, turbine engine components, and advanced composites.

The Phase IV program will modify and provide a production-ready HRRTR prototype which provides faster inspections through hardware and software improvements. These improvements incorporate off-the-shelf proven technology, cost, and time benefits over image intensifier-based RTR technology and film techniques currently used for identification of anomalous conditions. A Phase IV HRRTR detector system, with a larger field of view and faster acquisition time than the Phase III design, will be installed onto the Oklahoma City Air Logistics Center RTR gantry system to address nondestructive testing (NDT) needs for specific inspection applications such as detection of moisture in sandwiched honeycomb structures, and corrosion and cracking on principal structural elements on aircraft.

## Benefits

The payoffs of the development of improved, internal structure characterization inspection techniques will be the ability, which does not exist at the present time, to qualitatively monitor the quality of material during the development and production phases of materials and structures to be employed in these advanced applications, and to evaluate the integrity of these materials during their service life.

## Status

*Complete*
*Start date: November 1996*
*End date: November 1997*

## Resources

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# Neural Network Error Compensation of Machine Tools

**Contract Number: F33615-95-C-5541 ALOG Number: 1389**

## Statement of Need

Machine tools are serial-line, open-loop, kinematic chains. At one end of the chain is the part to be machined, and at the other is the cutting tool. One of the major functional requirements of this class of mechanisms is the ability to position the cutting tool with absolute positioning accuracy on the order of 0.001 percent of the total working volume. Improvement of machine tool accuracy is an essential part of quality control in manufacturing processes. There is a constant pressure on industrial manufacturers to produce high quality products while maintaining high productivity. A survey of major industrial manufacturers by Bowen and Duncan showed that 90 percent of the cost of insuring quality is due to scrapping/reworking of parts that do not lie within design tolerances. This adds to the cost of the part. Recently added emphasis has been placed on developing new methods that can help produce the product correctly the first time it is manufactured. These methods must be capable of providing the correct compensatory actions to the machine tools by actively monitoring the error sources of machining processes rather than passively inspecting machined parts.

The purpose of this Phase II SBIR is to develop a robust and cost-effective method to compensate for geometric and thermal errors in machine tools. It will make use of the self-learning properties of artificial neural networks (ANN) to predict the net positioning error at an arbitrary point in the workspace from knowledge of the error at some specified points in the workspace. This knowledge will be obtained from the measurement of geometric errors and their thermal variations as well as correlation with other process variables.



## Approach

A direct workspace identification technique will be adopted where the total error at the cutting tool is measured directly using a new calibration device called the Laser Ball Bar (LBB). This device will be used in conjunction with a neural network to rapidly build a model of the machine tool for a thermal duty cycle that simulated machining of large workpieces.

## Benefits

The proposed system will serve as a vehicle to enable the accuracy of commercial grade machine tools to be improved significantly and at an economical price.

## Status

*Active*
*Start date: August 1995*
*End date: February 1998*

## Resources

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*Contractor:*
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# Precision High Speed Machining With Vibration Control

**Contract Number: SPO900-94-C-0010 ALOG Number: 1261**

Metals

## Statement of Need

There are three main obstacles that limit the metal removal rates of high speed machines for production of complex, flexible aerospace structures with superior quality: 1) Vibration, leading to damaged part surfaces; 2) Low feed rates and accelerations leading to excessive slow down and time spent in cornering; and 3) Limited path accuracy at higher feed rates resulting in overshoot conditions. The objective of this program is to design, develop, and demonstrate a very agile and dynamically stable High Speed, High Feed Rate, 5-Axis Machine Tool for producing extremely flexible aluminum aerospace structures with superior quality, minimum weight, and reduced part cost.

## Approach

The approach will be to assemble a team consisting of Boeing, Ingersoll, Setco, Lucent Technologies, Manufacturing Laboratories, Inc. (MLI), and University of Florida. This team will establish the performance requirements of the machine tool, design and develop the vibration control and N/C controller technologies to be integrated onto the machine tool, fabricate and assemble the machine tool, and demonstrate its capabilities to the government and industry. Boeing is the program manager and will use its experience as leader in designing high speed machined aircraft parts and as a leader in the production implementation of high speed machining to drive the specific requirements of the machine tool. Ingersoll is a leader in manufacturing high speed machines for the automotive and aerospace industries, and brings to the table its experience for designing and manufacturing a 5-axis, 1200 ipm machine tool with 2g acceleration rates. Setco is a leading U.S. manufacturer of high speed spindles, and will design and fabricate the 36,000 RPM spindle to accommodate active spindle vibration control. Lucent Technologies will develop and fabricate an active spindle vibration control system to dampen out vibrations in the spindle shaft. MLI brings a wealth of experience in high speed machining technology to the table. MLI will provide the chatter recognition and control system to detect and control cutter vibration, active and passive structural vibration control to minimize vibration of the machine tool, and will develop the feed forward control system to maximize path accuracy at high feed rates and accelerations. Finally, the University of Florida's Machine Tool Research Center will provide a test bed for evaluating the component technologies developed under this project. The machine tool will be installed in Boeing's St. Louis Advanced Manufacturing Technology facility for the demonstration.

## Benefits

This high speed machine tool will allow evaluation of leading edge vibration control and path accuracy technology for the production of complex, extremely flexible part configurations with superior quality, minimum weight and reduced part count. Industry will benefit from learning which technologies should be specified in future machine tool procurements. The government customers will subsequently benefit from increased capability to produce lightweight aerospace structures at an affordable cost.

## Status

*Active*
*Start date: May 1994*
*End date: June 1998*

## Resources

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*Contractor:*
*McDonnell Douglas Corp.*

*JDMTP Subpanel:*
*Metals*

Metals

# Precision Machining Program

**Contract Number: F33615-94-C-4440 ALOG Number: 1271**

## Statement of Need

With today's requirements for higher speeds, lighter weights, smaller tolerances, and greater process flexibility and efficiency, traditional approaches for vibration reduction no longer suffice. Active Structural Control uses advanced algorithms embodied in microprocessors to drive actuators in opposition to structural vibration, providing suppression an order of magnitude greater than passive systems but without the attendant weight penalty. Once demonstrated on the factory floor, this technology will be marketed in both retrofit packages and new designs, either through existing distribution channels or through license agreements.

The objective of the Precision Machining Program is to investigate widely used machining operations, namely turning, boring, milling and grinding, and to design, fabricate and demonstrate integrated systems for reducing dynamic machine tool errors. The ultimate goal is to develop modular system components that can be installed as retrofits on large classes of machines for suppression of vibrations at the cutting tool-to-workpiece interface.

## Approach

The program is aimed at developing and applying active structural control technology to the basic machining operations of turning, boring, milling and grinding. For each of these basic machining operations, Advance Development Models will be designed, developed and tested under rigorous conditions. All demonstrations will be on the factory floor, using hardware and software that have been designed for compatibility with factory processes and robustness to real factory conditions.

## Benefits

The factory floor prototypes will suppress regenerative chatter from machining operations. In addition, they will reduce the effect of forced vibrations. The magnitude of reduction will depend on the workpiece and the cutting parameters. Suppression of chatter and reductions in forced vibration levels will allow the users to achieve higher levels of precision and productivity. The ultimate goal is to develop modular system components that can be installed as retrofits or to develop new designs, applicable to large classes of machine tools, for the suppression of vibrations at the cutting tool-to-workpiece interface.

## Status

*Active*
*Start date: July 1994*
*End date: December 1997*

## Resources

*Project Engineer:*
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*DARPA Funded*

*Contractor:*
*Lucent Technologies*

*JDMTP Subpanel:*
*Metals*

# Production Laser Peening Facility Development



**Contract Number: F33615-96-C-5624 ALOG Number: 1456**

## Statement of Need

The lifetime of turbine engine airfoils is of major importance to the Air Force, commercial engine manufacturers, and commercial airlines. Foreign object damage (FOD) and high cycle fatigue are serious concerns since they can result in the destruction of the engine, loss of aircraft, and possibly loss of life.

Several fatigue life enhancement techniques are currently in use on airfoils and other structures, most notably shot peening or glass bead peening. These techniques impart compressive residual stresses to a thin layer of the surface of the airfoil. If the compressive residual stresses can be driven deeper into the surface, the fatigue life enhancement would be even greater. This can be accomplished by using a high-energy laser pulse to generate shock waves on the surface, which is a process called laser peening. It provides an alternate fatigue life enhancement method that could possibly be used in cases where the use of another method is not possible.

The objective of this Phase II Small Business Innovation Research (SBIR) project is to extend the Phase I research to develop a state-of-the-art laser peening facility. It will be capable of meeting the near term production needs of the Air Force while providing a facility for the introduction of laser shock peening to other commercial markets. This effort will demonstrate the operation of an industrial grade, Class 1 laser system for laser shock processing and integrate it to an enclosed robotic work station to form a complete laser shock processing facility.



## Approach

The project is divided into three sequential phases. Phase I (17 tasks) is a six-month effort to resolve outstanding technical issues associated with the laser components, solidify the final design, and develop final system specifications. Phase II (six tasks) is a ten-month effort focusing on acquisition, assembly and subsystem checkout. Phase III (four tasks) is a two-month effort for system checkout and performance characterization.

## Benefits

This program will result in:

- A fourfold improvement in fatigue strength over untreated, damaged blades
- A broad range of possible applications
- An increase in a blade's detectable damage threshold, thereby decreasing maintenance repair costs

## Status

*Active*
*Start date: April 1996*
*End date: December 1997*

## Resources

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*SBIR Funded*

*Contractor:*
*LSP Technologies, Inc.*

*JDMTP Subpanel:*
*Metals*

# Rapid Laser Shock Peening Development

**Contract Number: F33615-97-C-5137   ALOG Number: 1531**

## Statement of Need

In the early stages of the application of laser shock peening, the manufacturing aspects of the process have not been developed to an acceptable level. One of the significant shortcomings of the current status of the process is the slow rate of processing. The major factor in this slow processing rate at this point in the technology is the application and removal of the opaque overlay system, in this case, paint. Current practice is to apply and remove the paint off-line, and when a number of shots are required on a part, this necessitates placing into and removing from the laser workstation, a part being laser peened several times before it is completed. This drastically slows the processing rate.

This Phase I Small Business Innovation Research (SBIR) project addresses this problem by developing a concept to apply and remove the paint in real-time, on-line for each shot. This will enable a part to remain in the workstation, being processed to completion, without interruption.

## Approach

1) Demonstrate the viability of placing and removing an opaque overlay on the surface to be laser peened within two seconds or less, and define the requirements to ultimately do this in one second or less.

2) Demonstrate shaping the laser spot to a square spot using optical -- not masking -- techniques and the use of this shape in a multi-spot pattern.

3) Demonstrate that the residual stress distributions using these methods are equivalent to those achieved by the current method of applying and drying the paint outside the workstation and with those obtained using round spots.

## Benefits

This effort will address issues directly related to processing throughput of laser shock peened parts. Increased throughput will drive down application costs making laser shock peening an affordable, attractive surface treatment process.



## Status

*Complete*
*Start date: April 1997*
*End date: October 1997*

## Resources

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*SBIR Funded*

*Contractor:*
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*JDMTP Subpanel:*
*Metals*

# Titanium Matrix Composite Turbine Engine Component Consortium (TMCTECC)



**Cooperative Agreement Number: F33615-94-2-4439  ALOG Number: 1286**

## Statement of Need

Modern aircraft performance is directly related to "thrust to weight" ratio of engines and the combined weight of the aircraft structure, systems, subsystems, and fuel. Titanium Matrix Composites can provide engine manufacturers and aircraft companies the capability of significantly reducing weight while providing increased performance. Unfortunately these materials are very expensive and the production base does not exist to affordably and routinely produce affordable, high quality components.

## Approach

The Titanium Matrix Composite Turbine Engine Components Consortium (TMCTECC) is a pre-competitive industry consortium consisting of Atlantic Research Corporation, 3M, Textron Systems, Pratt & Whitney, General Electric Aircraft Engines, and Howmet Corporation. The six member consortium is bound together by an agreement called the articles of collaboration which defines the relationship between the companies, intellectual property rights and more. The aim of this cost-shared program is to mature the TMC fabrication industry and deploy TMC's in advanced gas turbine engines. This work is being done in a manner that should assure the TMC supplier community is self sustaining without the need for government subsidy at program completion. This outcome will facilitate the ready availability of TMC material for a variety of defense and commercial applications without the need for long lead time industrial base maturation. The specific goal of this effort is to make this a stable and demonstrated "production ready" industry in time to significantly impact the Joint Strike Fighter (JSF).

TMCTECC is in the second phase of a three-phased program. Phase I, "Feasibility Establishment," provided fabrication demonstrations and TMC process development. Phase II, "Production Capacity Establishment," is establishing a TMC production capacity and providing performance demonstration for specific components. TMCTECC will accomplish this by implementing TMC material into components requiring an annual volume sufficient to stabilize the industry. A manufacturing base capable of producing 15,000 pounds per year can readily support the relatively small volumes anticipated for use in all engines/applications in the foreseeable future. The specific Phase II program goal of an annual capacity above 2,500 pounds will be demonstrated, a volume more representative of the anticipated military engine requirement over the next several years. In Phase III, "TMC Insertion & Market Expansion," component performance validation will be accomplished to assist TMC technology insertion into aircraft and engines.

## Benefits

This program will develop a cost-effective industrial infrastructure for TMC's and the related gas turbine engine hardware. Significant weight savings is projected for JSF.

## Status

*Active*
*Start date: August 1994*
*End date: August 1999*

## Resources

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*Air Force Funded*

*Contractor:*
*Titanium Matrix Composite Turbine Engine Component Consortium*

*JDMTP Subpanel:*
*Metals*

# Ultra-Thin Cast Nickel-Base Alloy Structures

**Contract Number: F33615-93-C-4305 ALOG Number: 710**

## Statement of Need

Many cast turbine engine components are manufactured thicker than structural design analysis require. Current state-of-the-art casting techniques are limited to 0.060-0.070 inches minimum thickness. Continued improvements in gas turbine technology will require development of lower weight structural components with higher metal temperature capability. The feasibility to cast small-scale ultra-thin structures in the range of 0.010-0.020 inches thick has been demonstrated. The need exists to exploit this technology for the cost-effective fabrication of reproducible and reliable large geometrically complex components. Although several processes have been used to demonstrate capability to cast thin-wall nickel-base castings, the optimum process has not been identified. The work to date has been limited to relatively small sub-element size pieces with little laboratory evaluation and no engine testing.

This program is aimed at applying advanced materials processing technology to the manufacture of propulsion and structural components. The program will begin with the casting process development/selection, process demonstration, and then hardware fabrication/qualification.

## Approach

The goal of this program is to develop cost-effective manufacturing processes capable of producing ultra-thin (10-20 mm) single-crystal cast components. The component selected to demonstrate the process technology is the F119 transition duct liner. A separate but parallel program is aimed at establishing a coating process for the liner. The liner portion of the program will be conducted in three phases with several subtasks per phase. In Phase I, a casting supplier and material will be selected for use in the program. A sub-element configuration will be designed for casting process development trials. Rapid prototyping will be employed for the sub-element tooling and solidification modeling, and intelligent process control will be used throughout the technical effort. Sub-elements and mechanical property specimens will be evaluated to assess the casting process selected in Phase I. In Phase II, a larger size subcomponent based on the Phase I results will be designed. The selected casting process shall be optimized and employed to cast subcomponents for laboratory and engine testing on the Component and Engine Structural Assessment Research (CAESAR) engine. Following engine test on CAESAR, the subcomponents will be evaluated and a cost analysis will be provided for producing a full-scale component relative to current Bill-of-Material configuration. A preliminary assessment of applicable repair methods for the cast subcomponent will be identified based on engine test experience, and selected repair methods demonstrated.

## Benefits

Ultra-thin cast nickel-base structural castings is a critical technology that will reduce engine weight, improve thrust-to-weight ratio, increase durability, and improve range. The current baseline F119 transition duct section is a multi-piece fabricated component consisting of 1,380 separate parts and 120 manufacturing operations. A cast one piece design will reduce this to 20 separate parts and 40 manufacturing operations. This technology is capable of manufacturing 100 percent retrofitable components. Modifications to existing Air Force and Navy weapon systems where lightweight components are required can use this enabling technology. This technology is also applicable to castings on commercial engines.

## Status

*Active*
*Start date: September 1993*
*End date: September 1998*

## Resources

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*Air Force Funded*

*Contractor:*
*United Technologies Corporation*

*JDMTP Subpanel:*
*Metals*

# Advanced Casting Technology for Low Cost Composites



**Contract Number: F33615-97-C-5124 ALOG Number: 1550**

## Statement of Need

Composite tooling costs have been identified as a high cost area especially in the prototype environment and as production rates continue to drop. Composite cure tools must produce dimensionally accurate parts (matching coefficient of thermal expansion) be affordable, and durable enough for production use. New technologies and methodologies are needed to develop composite processing tools that are low cost, highly durable, have compatible thermal performance characteristics, and short fabrication lead times.

## Approach

This STTR Phase I Small Business Innovation Research award will be directed towards patternless molding as a method to significantly reduce cost and lead times of invariable lay-up tool casting by eliminating hard pattern equipment. Integrally cast stiffeners will be investigated to create a method to reduce cost and lead time of tool substructures and to improve the heat transfer properties of the tools.

## Benefits

This technology will have the following benefits:

- Eliminate cost and lead time of hard patterns
- Lower casting material and machining costs and lead times
- Lower substructures costs and lead times
- Better heat transfer characteristics
- Shorter autoclave cycle times



## Status

*New Start*
*Start date: August 1997*
*End date: August 1998*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*Waukesha Foundry Incorporated*

*JDMTP Subpanel:*
*Composites*

Nonmetals

# Affordable Tooling for Composite Structures

**Contract Number: F33615-97-C-5142 ALOG Number: 1551**

## Statement of Need

Composite tooling costs have been identified as a high cost area especially in the prototype environment and as production rates continue to drop. Composite cure tools must produce dimensionally accurate parts (matching coefficient of thermal expansion) be affordable, and durable enough for production use. New technologies and methodologies are needed to develop composite processing tools that are low cost, highly durable, have compatible thermal performance characteristics, and short fabrication lead times.

## Approach

This STTR Phase I Small Business Innovation Research program will develop a new tooling system for composites, especially for affordable low production. The tooling system involves a novel two component system with a mold-face laminate and backup structure. The mold face laminate could then be separated from an adjustable accurate backup structure.

## Benefits

The anticipated benefits for this tooling system are low initial cost, very quick delivery, very good durability, and effective applicability in aerospace, defense, and commercial manufacturing scenarios.



## Status

*New Start*
*Start date: August 1997*
*End date: August 1998*

## Resources

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*SBIR Funded*

*Contractor:*
*Integrated Composites Incorporated*

*JDMTP Subpanel:*
*Composites*

# Affordable Tooling for Composite Structures

**Contract Number: F33615-97-C-5144 ALOG Number: 1554**

## Statement of Need

Organic matrix composites structural technology impacts virtually every current and new weapon system. These structures provide critical performance enhancements which enable the DoD to field superior weapons systems. Although organic matrix composites are used in a wide spectrum of vehicle structures, the high cost of these structures may severely limit the implementation of this critical technology to its fullest potential. Therefore, new technologies which allow for the affordable implementation of composite structures must be pursued.

Tooling costs have been identified as a high cost area especially in the prototype environment and as production rates continue to drop. Composite cure tools must produce dimensionally accurate parts, (match the coefficient of thermal expansion (CTE) of the part), be affordable to demonstrate the tooling approach in a prototype environment, and be durable enough to meet the requirements of production use. INVAR tools have been shown to meet thermal and durability requirements and are being used extensively on ongoing aircraft production programs. However, INVAR tooling is very expensive and requires significant fabrication lead times.

New technologies and methodologies are needed to develop composite processing tools that are low cost, highly durable, have compatible thermal performance characteristics, and short fabrication lead times. The new tooling technology and methodology should address the cost of fabricating both the tool face and substructure. It must provide all the capabilities of internal tooling points, scribe lines, and vacuum ports as available on current INVAR cure tools.

The technical objective of this Phase I Small Business Innovation Research (SBIR) is to develop and demonstrate low cost tooling concepts to allow broad applications of the novel localized resistive heating technology.

## Approach

The approach is a novel tooling and processing methodology of fabrication of polymer matrix composite structures. This methodology is based on a novel localized resistive heating concept developed by the Southern Research Institute. This proprietary heating technique applies heat only to the part being process and does not heat the tool except at the tooling surface.

## Benefits

Composite materials have already found widespread application in the commercial market. Improved quality and lower part cost are desired features whether the market is military or commercial. The concept developed will be applicable and beneficial to industries ranging from aerospace to automotive to medical.

## Status

*New Start*
*Start date: May 1997*
*End date: July 1998*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*Production Products Manufacturing*

*JDMTP Subpanel:*
*Composites*



Nonmetals

# Composites Affordability Initiative

**Cooperative Agreement Number:** **ALOG Number: 1433**

## Statement of Need

The Composites Affordability Initiative (CAI) is being structured as an agreement between the government and industry to jointly attack the issues and areas of cost associated with the use of composite materials in military systems. The DoD, primarily the Air Force and the Navy, are participating with the four major airframe manufacturers, Boeing, Lockheed Martin, Northrop Grumman and McDonnell Douglas, in an effort to jointly develop and mature the essential approaches to achieve major cost reductions in composites. This will be accomplished by addressing issues which cross the boundaries of cultural, business and technology domains from both the perspective of the government and industry. The management team will be structured as a Leadership Integrated Product Team (LIPT) using the principles of IPPD to accomplish required tasks via focus activity IPTs created to address specific topic areas/issues. This team will have total responsibility for the direction of the effort and all the member resources assigned to the program.

Initially, the CAI will focus on fixed wing-attack aircraft as they represent the most costly and structurally challenging usage of composites. The results will however, be applicable to other aircraft systems, both military and commercial, and could enhance composites use in services ground vehicle and ship applications. When these opportunities arise the membership of the CAI will be expanded to cover the new opportunities.

## Approach

All activities will be a collaborative effort with all CAI members sharing in the results of the effort, including the early concept and structural demonstration which will be used as check points for the design and process technologies required to attain the program goals. Members will share results of their IRAD and in-house efforts essential to achieve the CAI goals within the membership in a rare show of industry cooperation and support. Extensive use of shared facilities, government and industry, will be required in the early phases of the program with collocation of team CAI personnel necessary to most effectively accomplish the effort and participate in all aspects of the effort. Progress in achieving the goals of the effort will be measured through periodic demonstrations which will serve as major milestones in the initiative and will also serve as opportunities to migrate the validated approaches for cost reduction to system program offices and production application.

## Benefits

CAI activity will result in a major reduction in the cost of composite structures and expand their application in military systems. This can only be accomplished in collaborative effort between the government and industry. The active involvement of both parties, collaborative planning and shared development, early and frequent demonstrations with opportunities for early transition to production is the only approach to gain wide acceptance of the proposed new revolutionary airframe approaches.

## Status

*Active*
*Start date: July 1997*
*End date: To be determined*

## Resources

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*Lockheed Martin,*
*McDonnell Douglas*

*JDMTP Subpanel:*
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Nonmetals

# Composite Manufacturing Process Control System

**Contract Number: F33615-96-C-5627 ALOG Number: 1415**

## Statement of Need

Process controls are one of the key elements of building quality into an organic matrix advanced composite structure. Built-in quality reduces inspection, rework and scrap costs, increases reliability and results in lower overall acquisition costs. The majority of process controls investigated to date have focused on the curing process. However, process controls are needed on all of the manufacturing operations involved in the production of a composite part. Many composite structures, because of their complexity, continue to be manufactured by the hand lay-up process. Additional fabrication techniques also being used for ply lay-up include automated tape machines and tow placement machines. It is critical in the manufacture of a composite part that the plies be laid up in the proper sequence, proper location, and proper orientation, regardless of the manufacturing process. The objective of this project is to produce and install production prototypes of a composite manufacturing process control system (CMPCS).

## Approach

The proof-of-concept system was demonstrated in Phase I of this effort. Phase II brings together a team comprised of Assembly Guidance Systems, Inc., Bell Helicopter Textron, Inc. and Hexcel Structures to implement and refine the CMPCS system. The CMPCS provides accurate laser patterns showing placement locations for composite material and core. Non-value-adding costs of template fabrication, storage, retrieval, registration, deciphering, scribing, reworking, and training are eliminated with the CMPCS. The CMPCS operates with CDRH Class II laser safety, is portable and can be set up by one person in less than 15 minutes. The CMPCS provides automatic, in-process verification and documentation of each ply of composite material as it is being laid up. The CMPCS can function as a complete stand alone system or be integrated with other systems such as filament winders, automatic compaction systems or tape layers. Initial applications of the CMPCS began late 1996 on the C-17 wing-to-body fairings and the CV-22 rotor blades.

## Benefits

Composite materials have already found widespread application in the commercial market. Improved quality and lower part cost are desired features whether the market is military or commercial. The concept developed is applicable and beneficial to industries ranging from aerospace to automotive to medical to sporting goods.



## Status

*Active*
*Start date: May 1996*
*End date: May 1998*

## Resources

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*SBIR Funded*

*Contractor:*
*Assembly Guidance Systems*

*JDMTP Subpanel:*
*Composites*

# Design and Manufacture of Low Cost Composites -- Bonded Wing Initiative

**Contract Number: F33615-91-C-5729 ALOG Number: 155**

## Statement of Need

Future weapon systems will require even greater use of composite structures to meet the increasing performance and survivability requirements. Composite structures must be reduced in both acquisition and ownership costs to enable future weapon systems to achieve the performance necessary to counter future threats. There is little opportunity to reduce the cost of advanced composite aircraft structures using existing technologies due to limitations in design concepts and methods, material properties, and manufacturing processes.

Emerging, innovative new concepts, which will improve advanced composite manufacturing capabilities, will allow for innovative design techniques and will reduce the acquisition cost of composite structures. New structural configurations and design analysis methods need to be developed to use these improved manufacturing processes in an appropriate manner.

The purpose of these programs is to achieve a 50 percent reduction in the manufacturing cost of advanced composite structures with an attendant 25 percent reduction in the support cost. These efforts will develop the design/build technology necessary to reduce the cost of wing, fuselage, and engine structures for future aircraft. Each program will demonstrate the use of new emerging design, analysis, and manufacturing technologies implemented through a Concurrent Engineering/Integrated Product Development (CE/IPD) concept. The CE/IPD techniques developed within this initiative will also demonstrate the capability to reduce support costs for future structures that use similar techniques.

## Approach

Bell Helicopter Textron has demonstrated new materials and design manufacturing concepts identified as key to achieving a 50 percent reduction in the manufactured cost of the V-22 composite wing. The Bell concept established and implemented a new material form, the pultruded carbon rod, within a new design concept for wing stiffeners. Cost effective use of this rod was enabled through the development of the new manufacturing equipment. In addition to the implementation of the pultruded rod concept, Bell investigated all bonded construction, involving the bonding of thermoset to thermoplastic structures. Using a concurrent engineering format, Bell developed a highly integrated wing structure to reduce assembly cost. Fabrication costs were reduced by selecting the most cost effective match of manufacturing processes to structural requirements. Fabrication methods under this effort included resin transfer molding of stitched preforms and automated tape layup.

## Benefits

This project will reduce the manufacturing cost of advanced composite aircraft bonded wing structures by 50 percent.

## Status

*Active*
*Start date: September 1991*
*End date: June 1998*

## Resources

*Project Engineer:*
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*Air Force Funded*

*Contractor:*
*Bell Helicopter*

*JDMTP Subpanel:*
*Composites*

# Design and Manufacture of Low Cost Composites -- Engines Initiative

**Contract Number: F33615-91-C-5719 ALOG Number: 173**



## Statement of Need

Future weapons systems will require even greater use of composite structures to meet the increasing performance and survivability requirements. Composite structures must be reduced in both acquisition and ownership costs to enable future weapons systems to achieve the performance necessary to counter future threats. There is little opportunity to reduce the cost of advanced composite aircraft structures using existing technologies due to limitations in design concepts and methods, material properties and manufacturing processes. Emerging, innovative new concepts to improve advanced composite manufacturing capability will allow for innovative design techniques to reduce the acquisition cost of composite structures. This effort provided preliminary data by designing and manufacturing innovative advanced composite engine structures. Future designers will have the ability to verify cost-effective design/build methods. In order to assure that the decisions made have maximum potential to reduce acquisition cost while meeting all pertinent mission requirements, this effort focused on concurrent engineering methods. These methods will help achieve the most cost-effective match of structural requirements to material properties to manufacturing processes.

## Approach

The contractor used an integrated design and manufacturing approach to promote significant cost reductions and used the product development team approach to identify technologies that will reduce the manufactured cost of advanced composite engine structures. An overall design concept with a plan for further manufacturing development was established, with the most promising design, material form, fabrication, assembly, and inspection concepts selected. The manufacture of parts and test elements provided cost data to substantiate initial cost estimates. The contractor will design, fabricate, and assemble a full-scale engine duct validation test article. Costs associated with overall fabrication and assembly will be assessed and documented. Projected cost reductions will be compared to actual costs of fabricating the engine duct.

## Benefits

- 50 percent direct cost savings.
- 2 percent indirect cost savings.
- Reduce quality cost controls.
- Transition braiding and fiber placement to engine duct components.

## Status

*Active*
*Start date: August 1991*
*End date: September 1998*

## Resources

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*Air Force Funded*

*Contractor:*
*General Electric Company*

*JDMTP Subpanel:*
*Composites*

# Design and Manufacture of Low Cost Composites -- Fuselage Initiative

**Contract Number: F33615-91-C-5716 ALOG Number: 171**

## Statement of Need

Future weapon systems will require even greater use of composite structures to meet increasing performance and survivability requirements. Composite structures must be reduced in both acquisition and ownership costs to enable future weapon systems to achieve the performance necessary to counter future threats. There is little opportunity to reduce the cost of advanced composite aircraft structures using existing technologies, due to limitations in design concepts and methods, material properties and manufacturing processes. Emerging, innovative new concepts to improve advanced composite manufacturing capability will allow for design techniques to reduce the acquisition cost of composite structures. New structural configurations and design analysis methods need to be developed to use these improved manufacturing processes appropriately.

The objective of this effort was to develop the integrated design and manufacturing technology necessary to reduce the acquisition and support cost of advanced composite structure for aerospace vehicles. This effort demonstrated that through the use of new emerging design, analysis, and manufacturing technologies, implemented through Concurrent Engineering/Integrated Product Development (CE/IPD), it is possible to achieve a 50 percent reduction in the manufacturing cost of the advanced composite fuselage structure for transport aircraft. The CE/IPD techniques developed also demonstrated the capability to reduce support costs for future fuselage structures that use these same techniques.

## Approach

During Phase I, Boeing used an integrated design and manufacturing approach to promote significant cost reductions. They used the product development team approach to identify technologies that will reduce the manufactured cost of advanced composite aircraft structures. Evaluation criteria was established in areas of cost, weight, and manufacturing risk to support the concept recommendation at the end of Phase I. Upon completion of an overall design concept and its candidate materials and processes a plan for further manufacturing development in Phase II was established. This phase extensively developed the most promising design, material form, fabrication, assembly, inspection, and RM&S (reliability, maintainability, and supportability) concepts selected at the conclusion of Phase I. The manufacture of parts and test elements provided cost data to substantiate initial cost estimates. This phase culminated with a detailed definition of the full scale validation article.

## Benefits

This project reduced the manufacturing costs of advanced composite aircraft fuselage structures for large aircraft by 50 percent.

## Status

*Complete*
*Start date: July 1991*
*End date: October 1997*

## Resources

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*Air Force Funded*

*Contractor:*
*Boeing Company*

*JDMTP Subpanel:*
*Composites*

# Design and Manufacture of Low Cost Composites -- Wings Initiative



**Contract Number: F33615-91-C-5720 ALOG Number: 320**

## Statement of Need

Future weapon systems will require even greater use of composite structures to meet the increasing performance and survivability requirements. Composite structures must be reduced in both acquisition and ownership costs to enable future weapon systems to achieve the performance necessary to counter future threats. There is little opportunity to reduce the cost of advanced composite aircraft structures using existing technologies due to limitations in design concepts and methods, material properties and manufacturing processes.

Emerging, innovative new concepts, that will improve advanced composite manufacturing capabilities, will allow for innovative design techniques and reduce the acquisition cost of composite structures. New structural configurations and design analysis methods need to be developed to use these improved manufacturing processes in an appropriate manner.

The purpose of these programs was to achieve a 50 percent reduction in the manufacturing cost of advanced composite structures with an attendant 25 percent reduction in the support cost. These efforts developed the design/build technology necessary to reduce the cost of wing, fuselage, and engine structures for future aircraft. Each program demonstrated the use of new emerging design, analysis, and manufacturing technologies implemented through a Concurrent Engineering/Integrated Product Development (CE/IPD) concept. The CE/IPD techniques developed within this initiative also demonstrated the capability to reduce support costs for future structures that use similar techniques.

## Approach

The McDonnell Douglas Aircraft Company developed design concepts and manufacturing processes for a thin wing section typical of an advanced fighter wing. McDonnell Douglas identified a general structural design, specifically a multi-spar concept with monolithic load-sharing skins that showed maximum potential to achieve the cost reduction goals of this program. Within this general concept, variations for built-up substructure and wing upper and lower skins were examined for impact on manufacturing and support cost. This examination was conducted through trade study comparison of manufacturing processes. These include braiding, stitching, resin transfer molding, thermoforming, and thermoset/thermoplastic fiber placement. Integrated product/process development methods were used throughout this program to select and validate the design concepts, material systems, and manufacturing processes.

## Benefits

Anticipated payoffs include: lower cost, increased use of composites, more affordable composites, lighter weight structures, increased performance, and increased fatigue life.



## Status

*Complete*
*Start date: August 1991*
*End date: August 1997*

## Resources

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*Air Force Funded*

*Contractor:*
*McDonnell Douglas*

*JDMTP Subpanel:*
*Composites*

# Dynamic Polymer Composites

**Contract Number: F33615-97-C-5126 ALOG Number: 1536**

## Statement of Need

Decreasing defense budgets along with increasing commercial requirements necessitate the development of low cost organic matrix composite structures. A large percentage of the costs are associated with assembly and repair of composite structures. Currently, there are no available joining methods that lend themselves to quick and easy field assembly and repair of aircraft composites. Joining concepts are required that: 1) may be used under field conditions with a minimum of tools/equipment; 2) develop an adequate portion of the strength of the structural members themselves; 3) minimize or eliminate surface preparation; and 4) minimize the need for precise dimensional tolerances.

The objective of this project is to build upon the Phase I work to refine the concept and scaleup, and to ready the concept for factory floor or field operations.

## Approach

This project will address applications design, manufacturing and cost impact. Structural connector will be tested to determine capabilities. The prototype will be field validated.

Dynamic Polymer Composite's (DPC's) patent has been published and the details are now public. No further protection is offered by suppressing the write-up of the formal demonstration of DPC connections. An abstract was submitted to MT entitled, "Demonstration of a Dynamic Polymer Composite Connector." This paper was sent for review and approval to be presented at the American Society for Composites 12th Annual Technical Conference in Dearborn, Michigan, in October 1997.

## Benefits

The DPC connectors create a smooth stress flow between cylindrical structural members. The DPC connectors have high-module fibers that are pre-stressed during manufacture to be released during assembly when the polymer matrix is heated. Dynamic polymer composite connectors enable a composite airframe to be component assembled.



## Status

*Active*
*Start date: April 1997*
*End date: April 1999*

## Resources

*Project Engineer:*
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*SBIR Funded*

*Contractor:*
*The Technology Partnership*

*JDMTP Subpanel:*
*Composites*

# Enhanced Pultruded Composite Materials

**Contract Number: F33615-96-C-5629   ALOG Number: 1467**

## Statement of Need

Most pultrusion research studies to date, including that of the previous Phase I Wright Laboratory sponsored research (Aerospace Sciences Research and Development, F33615-91-C-5727), have examined simple pultruded shapes (e.g., simple flat or circular geometries), and have related processing conditions of these shapes to the expected mechanical properties of the composite. However, most design applications require products in more complex shapes, and unfortunately for composite materials, knowledge of composite material properties for simple shapes does not imply knowledge of the mechanical properties for the more complex shapes. Complex shaped composites need to be carefully designed for proper fiber placement and alignment, in addition to all those factors that normally affect pultruded composites. The objective of this effort is to manufacture composite materials in an optimized engineering design geometry.



## Approach

A major expansion of the previous research will be to manufacture (pultrude) composite materials in optimized engineering design geometries such as I-beams, T-beams, L-beams, or hollow tubes. The use of composite materials in wide ranging design applications will make the study of structural geometries necessary. The manufacture of these shapes will require the use of fiber fabric. In the past research (Phase I) only unidirectional (longitudinal oriented) fibers were employed. The use of fabric will provide an opportunity to vary the mechanical properties as a function of fiber orientation (direction). The research will also use "hybrid" glass/graphite fiber. After manufacturing these shapes for a variety of operational pultrusion parameters (pull speed, fiber volume lay-up and hybridization, and die temperature profile), the composite materials will be tested to determine the mechanical/physical properties.

## Benefits

This research will develop a basic understanding of the manufacture of complex pultruded shapes. This understanding will tie the properties of useful structural shapes to those pultrusion process conditions used to produce them. In addition, the structural shapes produced will be studied to provide the most desirable composite material properties by taking advantage of the best combination of properties from both graphite and glass fiber. By using this hybrid composite, using the best of both graphite and glass, the pultrusion process can be optimized to produce useful structural shapes.

Nonmetals

## Status

*Active*
*Start date: May 1996*
*End date: April 1998*

## Resources

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*Air Force Funded*

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*JDMTP Subpanel:*
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# Fiber Placement Benchmark & Technology Roadmap

**Cooperative Agreement Number: F33615-95-2-5563    ALOG Number: 1470**

## Statement of Need

Affordability is the key challenge facing today's aerospace industry. While the weight savings benefits of composite structures have been well documented, part cost remains a major challenge. Fiber placement offers the potential to significantly reduce material waste and labor costs in comparison to conventional part fabrication methods. In addition, fiber placement provides a unique opportunity to optimize structural efficiency and to fabricate large, complex parts not feasible for fabrication by conventional methods. However, the capabilities of fiber placement are not fully understood and the complete benefits of fiber placement cannot be fully realized.

The objective of this program was to benchmark the current state-of-the-art in production fiber placement capabilities and to provide a technology roadmap for composites automation technology into the next century.

## Approach

The benchmarking effort was documented in a series of fiber placement manuals which provide cost and capability data to optimize designs for the fiber placement process and provide processing data required for repeatable, high quality manufacturing.

## Benefits

This effort will reduce material waste and labor costs and optimize structural efficiency. It provides guidelines to the design community and a roadmap for the machine tool builders around fiber placement technology.



## Status

*Complete*
*Start date: November 1995*
*End date: November 1997*

## Resources

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*DARPA Funded*

*Contractor:*
*McDonnell Douglas*

*JDMTP Subpanel:*
*Composites*

# Field Level Repair/Joining of Composite Structures

**Contract Number: F33615-97-C-5125  ALOG Number: 1537**



## Statement of Need

Decreasing defense budgets along with increasing commercial requirements necessitate the development of low cost organic matrix composite structures. Affordability includes all steps of the manufacturing process from starting materials to final inspection. A large percentage of the costs are associated with assembly and repair of composite structures. Currently, there are no available joining methods that lend themselves to quick and easy field assembly and repair of aircraft composites. Joining concepts are required that: 1) may be used under field conditions with a minimum of tools/equipment, 2) develop an adequate portion of the strength of the structural members themselves, 3) minimize or eliminate surface preparation, and 4) minimize the need for precise dimensional tolerances. The objective of this project is to develop an ultrasonic repair/joining technique for field repair of advanced composite structures.

## Approach

The approach will be to combine ultrasonic lamination and Z-fiber insertion into a qualified repair process for an advanced composite system such as the F-22. The program is scheduled to construct and demonstrate a prototype field repair unit.

## Benefits

Composite materials have already found widespread application in the commercial market. Improved quality and lower part cost are desired features whether the market is military or commercial. The concept developed herein is applicable and beneficial to industries ranging from defense and commercial aerospace, to automotive, civil structures, and electrical component industries.



## Status

*Active*
*Start date: May 1997*
*End date: September 1999*

## Resources

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*SBIR Funded*

*Contractor:*
*Foster-Miller Incorporated*

*JDMTP Subpanel:*
*Composites*

# Field Repair/Joining of Composite Aircraft Using Ultrasonic Methods

**Contract Number: F33615-96-C-5100 ALOG Number: 1421**

## Statement of Need

Decreasing defense budgets along with increasing commercial requirements necessitates the development of low cost organic matrix composite structures. Affordability includes all steps of the manufacturing process from starting materials to final inspection. A large percentage of the costs are associated with assembly and repair of composite structures. Currently, there are no available joining methods that lend themselves to quick and easy field assembly and repair of aircraft composites. Joining concepts are required that: 1) may be used under field conditions with a minimum of tools/equipment, 2) develop an adequate portion of the strength of the structural members themselves, 3) minimize or eliminate surface preparation, and 4) minimize the need for precise dimensional tolerances. The need exists to have an effective field repair for composite structures. The F-22 System Program Office has expressed high-level interest in this program and a nondisclosure agreement is in progress with Foster-Miller to have Lockheed evaluate the repair process.

## Approach

This Small Business Innovation Research (SBIR) Phase I project is developing a unique repair/joining method that eliminates fasteners, does not require autoclave or oven cure, and is equally compatible with field and shop floor operations. The proposed process utilizes ultrasonic energy for two discrete operations: in-situ deposition of a thermoplastic composite laminate patch/splice and insertion of through-thickness pins around the periphery of the patch/splice to react to peel stress concentrations and increase bondline strength.

## Benefits

If successful, this program would provide a cost effective method of composite field repair while retraining superior performance characteristics. Composite materials have already found widespread application in the commercial market. Improved quality and lower part cost are desired features whether the market is military or commercial. The concept developed herein will be applicable and beneficial to industries ranging from defense and commercial aerospace, to automotive, civil structures, and electrical component industries.



## Status

*Complete*
*Start date: May 1996*
*End date: February 1997*

## Resources

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*SBIR Funded*

*Contractor:*
*Foster-Miller Inc.,*

*JDMTP Subpanel:*
*Composites*

# Filmless Radiography for Aerospace Applications

**Contract Number: F33615-97-C-5122 ALOG Number: 1547**

## Statement of Need

Radiography is frequently used to assess the quality of aerospace parts and assemblies. In addition, radiography is used extensively by the Air Force at the field and depot level to evaluate the condition of in-service aircraft. X-ray inspections are a vital part of maintaining the fleet and are used for detecting entrapped water or moisture, foreign objects (FO), and cracks. It is also used for bonded assembly inspection. Conventional X-ray inspection methods required the use of film packages and associated processing chemicals. The amount of X-ray film used in the Air Force has been estimated to cost over $1 million per year. This cost does not include the cost of film processors, film processing chemicals, or silver recovery units necessary to recover environmentally hazardous by-products of the film development process. In addition, significant man-hours are expended to continuously maintain and manage film processing and archiving. This effort will evaluate the feasibility to develop or modify a filmless radiography system with digital storage capability for aerospace structures and transition it to Air Force depots and field environments.

## Approach

The purpose of this effort is to develop, demonstrate and implement a nondestructive evaluation (NDE) capability to eliminate or significantly reduce the use of radiographic film, chemicals, and ancillary equipment used in the process of developing, viewing, and storing radiographic images of aerospace structures at Air Force Air Logistic Centers (ALCs) and field environments. This project will develop a digital process that uses an imaging plate and laser scanning technology to produce high precision digitized images. The digital data is imaged in video format where it can be viewed on a high resolution monitor, archived on optical disk, or converted to a hard copy. The imaging plates can be erased and reused, eliminating the costs associated with consumable film. The prototype filmless radiography system will be modified to incorporate Air Force aircraft inspection, image storage, and X-ray procedure modification requirements. Initial implementation will occur at Warner Robins ALC and Seymour Johnson AFB.



## Benefits

The implementation of Filmless Radiography will result in reduced operation cost (an estimated savings of over $1 million per year) and reduced hazardous chemical handling and disposal costs at Air Force ALCs and field depots.

## Status

*Active*
*Start date: February 1997*
*End date: December 1997*

## Resources

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*Air Force Funded*

*Contractor:*
*Liberty Technologies, Incorporated*

*JDMTP Subpanel:*
*Composites*

# High Temperature Bagging/Sealant Materials for Composite Manufacturing

**Contract Number: F33615-96-C-5626 ALOG Number: 1457**

## Statement of Need

As temperature requirements continue to increase on Department of Defense weapons systems, new materials have been developed which offer increased structural performance at elevated operational temperatures. However, these matrix systems are typically processed at temperatures greater than 600° Fahrenheit and pressures of 200 psi and tend to degrade current ancillary processing materials such as bagging materials and sealants. This may cause failure of the bagging material or sealants during processing and may lead to poor part quality and increased costs. Also, as composite components become large and more complex, bagging materials must be available in sufficiently large sizes to eliminate the need for seaming which can also lead to bag failures. The tooling required for larger parts also requires longer heat up times which further increases the time the processing materials are exposed to elevated temperatures. In order to efficiently use organic matrix resins which process at elevated temperatures, production hardened ancillary processing materials must be available. The objective of this project was to develop bagging and/or sealant formulation for use with high temperature (greater than 600° F) curing of aerospace quality advanced composite structures.

## Approach

The main approach was to formulate a high temperature resin system that can be processed. This was done by investigating improvements of silicone rubber fluoropolymers, polymides, fluoro or polyethers, or polysultones polymers. During this program, over 500 test samples were prepared with various permutations of formulations of bagging materials and sealants.

## Benefits

A high temperature bagging/sealant system (750°F) would allow the use of reusable bags to significantly reduce the time and cost of fabricating high temperature composites. This will provide the Air Force and its contractors a production ready and proven high temperature capability which does not currently exist. This will allow for the implementation of high temperature composite materials into systems applications which have not been possible before.



## Status

*Complete*
*Start date: April 1996*
*End date: January 1997*

## Resources

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*SBIR Funded*

*Contractor:*
*Utility Development Corporation*

*JDMTP Subpanel:*
*Composites*

# Manufacture of Thermoplastic Composite Preferred Spares



**Contract Number: F33615-91-C-5717 ALOG Number: 172**

## Statement of Need

The use of advanced composites in new weapon systems has dramatically increased. Advanced composites help achieve the desired goals of increased range, speed, payload, and supportability. The expanded application of composites into more of the airframe's structures introduces important rate production factors such as tool fabrication lead times and life, part reproducibility and integrity, tooling materials, etc., all of which are important considerations to overall manufacturing costs. In many cases, the component design, tool design, and tool manufacturing are far more costly than producing the parts themselves, especially when lot sizes are relatively small. This program focused on the use of computer-aided manufacturing technologies to develop and validate an integrated design/manufacturing system for noncritical structural components. This effort will permit the Air Logistics Centers (ALCs) to efficiently redesign and develop composite secondary structure by providing an automated design and analysis capability. This will reduce the risk and span time for replacement of high maintenance items.

## Approach

The Integrated Product Manufacturing System (IPMS) is aimed at the designer, analyst, manufacturing engineer and tool designer. Its intended use is the redesign of existing secondary, non-flight-safety critical metal aircraft structure to composites. The IPMS accepts as inputs part geometry, design constraints and production requirements. It automates some drafting and analysis functions, and uses a standard format to share loads, geometry, material properties and other information. These are used to develop part and tool designs, specifications, fabrication instructions and high level cost and schedule information.

Validation of the system was accomplished by using it to generate examples of part design and material/fabrication guidelines for airframe thermoplastic components which have been previously designed and manufactured on other programs, followed in Phase III by using the IPMS to develop designs for the Phase III demonstration articles. Phase III of this effort will establish a repair and limited remanufacturing capability for the C-130 aft nose landing gear door at Warner Robins ALC, and for the C-135 nose wheel gear door at Oklahoma City ALC. A limited production run will be conducted at the ALCs to provide training for ALC personnel, establish valid cost projections, and validate the IPMS developed manufacturing and process guidelines.

## Benefits

This program successfully demonstrated the capability to redesign an existing metal aircraft part to composites at up to 25 percent reduction in effort.

## Status

*Active*
*Start date: September 1991*
*End date: December 1997*

## Resources

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*Air Force Funded*

*Contractor:*
*Northrop Grumman*

*JDMTP Subpanel:*
*Composites*

# Manufacturing Technology for Multifunctional Radomes

**Contract Number: F33615-93-C-4312 ALOG Number: 655**

## Statement of Need

Multifunctional structures pose many unique and challenging problems related to manufacturing and assembly issues associated with low radar cross section radomes including: processing of multi-layer structure, tight tolerances required to meet electrical performance, number of processing cycles, and application of lightning strike protection materials. This program examined affordable solutions to these unique problems associated with radomes. The objectives are to establish and validate reproducible and affordable processes for the manufacture of low observable radomes. The specific goals are to meet current performance specifications while reducing the production costs, assembly variability, and production risks. This technology development will be applicable to the retrofit of radomes for existing aircraft as well as advanced fighters with low radar cross-section.

## Approach

To reach these objectives, a three-year, three-phase effort was defined. The first phase evaluated alternative manufacturing processes utilizing new low loss, low dielectric materials. During this phase the electrical performance of the selected materials and construction were defined. Additionally, a cost-benefit analysis was conducted and projected savings were compared to the baseline structure. The second phase provided manufacturing verification by utilizing the materials and concepts from Phase I to define tooling and assembly approaches. A full-scale radome was manufactured. Costs were tracked to provide a benchmark for measuring progress in realizing the projected cost and producibility benefits. In the third phase, additional full-scale components will be fabricated utilizing the materials, methods, tooling and assembly techniques established in Phase II. Testing will be conducted and the results will be compared to requirements.

## Benefits

This effort offers cost-effective solutions to the unique fabrication and assembly challenges associated with low radar cross section radomes. The approach demonstrated under this effort will meet or exceed all current specifications, and provide for a 30 percent reduction in acquisition cost and a 50 percent reduction in assembly span time versus the baseline.

## Status

*Active*
*Start date: September 1993*
*End date: December 1997*

## Resources

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*Air Force Funded*

*Contractor:*
*Lockheed Advanced Development Company*

*JDMTP Subpanel:*
*Composites*

# Microwave Curing for Reversible Bonding of Composites

**Contract Number: F33615-97-C-5139 ALOG Number: 1539**

## Statement of Need

The Manufacturing Technology Division aggressively pursues advances in manufacturing technology which have broad applicability to the affordability and performance of Air Force systems. The focus of this general topic is to allow opportunities for major breakthroughs in the following areas: Composites Processing & Fabrication, Electronics Processing & Fabrication, Metals Processing & Fabrication, Advanced Industrial Practices, and Manufacturing & Engineering Systems. New processing techniques, variability reduction tools, affordability improvements, manufacturing simulation and modeling, are a few examples of the types of proposals that are desired. The emphasis is on innovation, the ability to achieve major advances and defense/commercial applicability.

The objective of this project is to use reversible polymeric adhesive bonding using variable frequency microwave energy. This would allow military and civilian aircraft manufacturers and operators to assemble, inspect and maintain their aircraft more cost-effectively.

## Approach

During Phase I, Aerotech will demonstrate the feasibility of the reversible bonding process by bonding and dis-bonding thermoplastic and thermoset parts using thermoplastic peek powder as an adhesive. The goal of the project is to develop, test and validate process and equipment for reversible bonding of thermoplastic and thermoset composite using microwave (MW) energy for use in military and civilian applications. The parts that will be demonstrated in Phase I consist of test specimens which are planar. Dis-assembly of specimens joined with the thermoplastic adhesive will also be demonstrated during Phase I. The testing that is planned for Phase I includes lap shear tests of the bonded specimens and C-scan (ultrasonic imaging ) tests of the bonds. In addition, Aerotech will collaborate with Oak Ridge National Laboratory for manufacturing technology where work in microwave curing has been in progress in the past few years.

## Benefits

Variable frequency microwave radiation (VFMW) has been shown to produce more uniform heating of parts which ensures reduced thermal stress, reduced warping and controlled bubble formation. One of the main advantages of using microwave heating for thermoplastic adhesive curing is that the process is reversible.



## Status

*Active*
*Start date: April 1997*
*End date: December 1997*

## Resources

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*SBIR Funded*

*Contractor:*
*Aerotech Incorporated*

*JDMTP Subpanel:*
*Composites*

# Novel Low Cost Thermosets for Advanced Aerospace Composites

**Contract Number: F33615-96-C-5628 ALOG Number: 1455**

## Statement of Need

Decreasing defense budgets along with increasing commercial requirements necessitate the development of low cost organic matrix composites. Affordability includes all steps of the manufacturing process from starting materials to final inspections. New or modified materials must be able to produce aerospace quality components at a minimal cost independent production quantity. The process starts with the resin matrix. Subsequent manufacturing operations, including tooling and autoclave requirements, are dictated by the resin chemistry. Eliminating the need to process in autoclave environments will have a direct impact on cost reduction. The need exists for the development of resin chemistry which will be amenable to room temperature curing graphite reinforced composite structures, but which subsequently possess the same characteristics as today's state-of-the art 3500 epoxy systems.

## Approach

This project will significantly reduce the costs in advanced aerospace composite fabrication. This objective will be met by using rational chemical design principles to engineer novel low temperature cure liquid crystal autoclave cure cycling. Designed from the molecular level, Aspen's new liquid crystal thermoset system represents a maximum opportunity for significant cost reduction in advanced aerospace composite fabrication, meeting the challenge of high temperature performance with reduced processing costs and increased damage tolerance. The novel liquid crystal thermoset class initiates a close functional group packing density, allowing complete crosslink conversion at much lower temperatures than the polymer's final glass transition temperature. The result is a high temperature, high strength polymer cured at or near room temperature with enhanced damage tolerance.

## Benefits

Composite materials have already found widespread application in the commercial market. Improved quality and lower part cost are desired features whether the market is military or commercial. The concept developed will be applicable and beneficial to industries ranging from aerospace to automotive to medical to sporting goods and concerns.

## Status

*Active*
*Start date: April 1996*
*End date: February 1998*

## Resources

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*SBIR Funded*

*Contractor:*
*Aspen Systems Incorporated*

*JDMTP Subpanel:*
*Composites*

Nonmetals

# Oxidation Resistant Coating Application

**Contract Number: F33615-93-C-5309 ALOG Number: 711**

Nometals

## Statement of Need

The objective of this program was to establish and demonstrate the manufacturing technology required to produce production-ready radar absorbing material (RAM) coatings that are significantly improved over current coatings. The goal of the team was to establish coatings for these applications with higher temperature oxidation resistance, improved durability, improved electromagnetic performance, reduced manufacturing costs, and reduced weight compared with current state-of-the-art coatings. The first phase of this program used a team of contractors consisting of MSNW Inc. as prime contractor and Allison Engine Co., Hughes Missile Systems Co., United Technologies Research Center, and Williams International as major subcontractors. In Phase I, the team evaluated and demonstrated application methods for a range of high temperature RAM coatings on a variety of substrate materials for both manrated and non-manrated applications. These new coatings are compared against current contractor team state-of-the-art coatings as part of this program.

## Approach

The program was divided into three phases.

• Phase I – Process Evaluation: Consisted of defining and evaluating the coating compositions, fabrication approaches, and production applications of composites for the purpose of defining primary coating systems and improvement opportunities.

• Phase II – Process Optimization and Scale-Up: Consisted of fabricating and testing panels, establishing nondestructive evaluation techniques, and scaleup and testing of the proposed coating process.

• Phase III – Production Demonstration: Consisted of a limited production run of full-scale components, quality and performance verification, repair assessment, implementation planning, and material process specifications.

Cost benefit analyses were performed and updated in each phase of the program.

## Benefits

Program goals:

- Higher temperature oxidation resistance.
- Improved durability.
- Improved electro-magnetic performance.
- Reduced manufacturing costs.
- Reduced weight.

Nonmetals

## Status

*Complete*
*Start date: September 1993*
*End date: September 1997*

## Resources

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*Air Force Funded*

*Contractor:*
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*JDMTP Subpanel:*
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# Rapid Manufacture of Thermoplastic Radomes

**Contract Number: F33600-90-G-5308 ALOG Number: 307**

## Statement of Need

Current technology for radomes and antennas use composite materials consisting of thermoset resin systems reinforced with either glass, quartz or aramid fibers. The use of thermoset composites have created certain chronic fabrication and long-term durability and environmental problems which have resulted in increased cost and decreased reliability and maintainability. These chronic problems with thermoset composite methods manifest themselves in four main areas: 1) unacceptable moisture absorption which decreases performance, 2) inadequate toughness and impact resistance, 3) severe rain erosion unless protected by a coating, and 4) high fabrication and repair costs.

This task developed a flight-capable prototype radome constructed of thermoplastic composite materials resistant to the chronic problems found in thermoset composite radomes. In addition, design data, processing procedures, manufacturing techniques, and quality assurance requirements were generated that are necessary for reliable and consistent fabrication of thermoplastic composite materials into solid and multilayer sandwich radomes. The data and processes validated and documented are applicable to a broad range of radome structures and systems.

## Approach

This was a joint effort between the Wright Laboratory's Manufacturing Technology Division and the Air Force Materiel Command 2762 Logistics Squadron. This task: 1) built off current materials characteristics definition projects (PRAM), 2) produced multiple radome applications for demonstration (solid/honeycomb), 3) optimized rapid manufacturing techniques and processes, 4) demonstrated and verified results, and 5) developed a systems application (73 radomes per RC-135 A/C). The effort also established methods to transfer the validated technology to other systems.

## Benefits

This program groups radomes into families, improves radome system supportability, reduces electronic system performance degradation, optimizes rapid manufacturing techniques/processes, and reduces acquisition costs.



## Status

*Active*
*Start date: March 1993*
*End date: December 1997*

## Resources

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*Air Force Funded*

*Contractor:*
*E-Systems Incorporated*

*JDMTP Subpanel:*
*Composites*

# Resin Transfer Molding Rapid Prototyping and Tooling (RaPat)

**Cooperative Agreement Number: F33615-95-2-5558 ALOG Number: 1471**



## Statement of Need

Resin Transfer Molding (RTM) is demonstrating itself as having a high potential for reducing the cost and expanding the application of composites to aerospace structures, but the immaturity of the technology and the lead time currently needed to develop structures is greatly retarding its application. This lead time and the associated technical risks of new designs and manufacturing technology often preclude RTM from consideration on new military aircraft programs. Reduction of developmental lead times to six to twelve months through a methodology of rapid prototyping of tooling and components will greatly expand the opportunity to use RTM.

## Approach

The objective of this effort is to reduce the cost and lead times to design and produce RTM prototype tooling and components. The RaPat Program integrates rapid prototyping technologies for the manufacture of tooling for preforming and molding with resin materials and a structures methodology to deal with nontraditional low temperature curing materials as well as conventional RTM materials. This program brought together a team lead by Dow-United Technologies Composite Products, Inc. and supported by Sikorsky Aircraft Corporation, Lockheed Advanced Development Company, and the United Technologies Research Center to address the resin transfer molded parts for advanced military aircraft through rapid prototyping technologies.

The program investigated rapid prototype tooling approaches such as: stereolithography, selective laser sintering, laminated object manufacturing, three-dimensional printing, direct shell production casting, metal deposition, cast tools, droplet deposition and laminate tools.

The feasibility of using the RP tooling approaches for fabricating RTM tools will be demonstrated through the manufacture of two components, a fixed wing part (F-117 access panel) and a rotary wing part (Comanche transmission support fitting). This effort is sponsored with funds from the Defense Advanced Research Projects Agency.

## Benefits

The benefit of this effort will be a reduction in part production lead time by 6-12 months, and a reduction in tooling costs by 25 percent.



## Status

*Active*
*Start date: September 1995*
*End date: December 1997*

## Resources

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*DARPA Funded*

*Contractor:*
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*Composite Products, Inc.*

*JDMTP Subpanel:*
*Composites*

# Flat Panel Displays

**Contract Number: Numerous** **ALOG Number: Numerous**

## Statement of Need

This project constitutes a portion of the $580 million National Flat Panel Display (FPD) Initiative, a program designed to help develop suppliers that are competitive in commercial flat panel markets and willing to provide the necessary early, assured and affordable access. Of the $110 million Defense Production Act contribution to the initiative, $30 million will be allocated under this project for Title III market incentives to stimulate the purchase of flat panel displays.

The objective is to support the development of a viable domestic flat panel display industry, which to date has been overwhelmed by strong Japanese competition. High performance Active Matrix Liquid Crystal Displays are being utilized in the F-22 and other various Department of Defense cockpit modification programs involving both fixed and rotary wing aircraft. Cathode ray tube (CRT) technology has dangerous shortcomings in the cockpit environment, where display responsiveness and full sunlight readability are critical to combat performance. Flat panel displays solve these shortcomings with greatly improved brightness, color, lower weight, higher reliability, and greater overall performance.

## Approach

This program is being designed to facilitate the insertion of FPDs into avionics and other military-related applications. Military users will be given financial incentives to insert domestic FPDs into their systems. Incentives may be in the form of reduced costs for earlier purchases for the systems, or Title III may defray the costs of qualifying the domestically produced FPD for the users' systems. The following military weapon systems are involved with this project: Apache Longbow, C-141, F-18/AV-8B, F/A-18E/F, UH-60Q, CH-47, P-3, SOF aircraft, and the Army's Driver Vision Enhancer.

## Benefits

As the National Flat Panel Display Initiative helps to establish the domestic manufacturing base of this critical technology, this project seeks to expand the actual defense market for these devices in a time period which will be critical to early sales by these American companies. Concurrently, the military service program offices and their contractors can be aided by reduced costs of acquisition and integration for domestically produced flat panel displays. The technology transfer and insertion of this technology are expected to pay big gains for the military services and domestic industry.

## Status

*Active*
*Start date: August 1994*
*End date: April 1998*

## Resources

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*Title III Funded*

*Contractor:*
*Numerous*

# High Purity Float Zone Silicon

**Contract Number: F33733-93-C-1014 ALOG Number: 1304**

## Statement of Need

Currently, there is no domestic producer of high purity float zone (HPFZ) silicon. HPFZ silicon is vital to the manufacture of infrared and laser seeker detectors, vidicons, and high-power switching devices. The silicon material for such devices must be of much higher purity and quality than needed for even the most advanced integrated circuits, and 10,000 times greater than for electronic silicon.

The objective of this project is to re-establish a high-quality, low-cost domestic capability to produce high purity float zone (HPFZ) silicon. The technical objective of this project is to establish a domestic capability to produce up to and including 100 mm (~4 inch) diameter HPFZ silicon ingots. All material produced meeting the Title III Material Specification must be greater than 2,000 ohm-cm (n-type). In order to satisfy the exacting requirements for vidicons and infrared detectors, the contractor must demonstrate the capability to produce material greater than 25,000 ohm-cm (p-type). Product and process improvements will also be pursued to achieve greater quality and yields needed to be competitive in the global market.

## Approach

The Title III project seeks to establish a commercially viable production capacity through a phased development approach. First, the contractor will establish and demonstrate its capability to produce float zoned silicon. Next, it will scale up its production capacity and qualify its process to achieve material specifications and ISO 9002 certification. Finally, the contractor will implement cost reduction and marketing efforts while achieving a minimum production capacity of 6,000 kilograms per year. This final phase includes two one-year purchase commitment periods during which the government commits to purchase up to 3,000 kgs if the contractor is unable to sell the product to commercial or defense users.

## Benefits

This Title III project will assist in the establishment of a domestic producer of a key component in the advancing electronic device market. HPFZ silicon is necessary to meet the increasing demand for high quality, high purity semiconductor material. This project is designed to result in a commercially viable, domestic producer able to compete for a share of the global commercial and defense markets.

## Status

*Active*
*Start date: November 1993*
*End date: June 1999*

## Resources

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*Title III Funded*

*Contractor:*
*UniSil Corporation*

# Semi-Insulating Gallium Arsenide Wafer

**Contract Numbers: F33733-94-C-1017/1019/1020 ALOG Numbers: 1301/1302/1303**

Title III

## Statement of Need

The objective of this project is to assure a viable world-class domestic manufacturing capability to produce semi-insulating gallium arsenide (SI GaAs) substrates in support of Department of Defense (DoD) and commercial requirements. Primary applications for SI GaAs include microwave and millimeter wave integrated circuits. The material is an enabling technology for a variety of defense weapons systems. Title III incentives will be used to encourage investment by domestic companies to improve the quality of their product and the efficiency of their production processes.

## Approach

Each contractor has a unique technology of wafer production, providing a lower overall risk for the project. Common features of the contracts include a 24-month initial phase during which aggressive marketing and product improvement plans will be implemented. Qualification will occur at four DoD ion implant and epitaxial foundries. Each contractor will provide ISO 9000 certification during the initial phase. The companies' production capacity will be scaled up to 800,000 square inches of SI GaAs wafers. Phase II consists of two one-year purchase commitment periods during which the government will agree to purchase 175 to 300 ksi of wafers from each contractor if that amount is not sold to defense or commercial customers. Also, the contractors will receive sales incentives for expanded sales during this period.

## Benefits

Japanese dominance of both the world and U.S. markets discourages domestic investment in GaAs wafer production, in spite of the fact the U.S. market accounts for approximately 70 percent of the world demand. This Title III project will counter the effects of foreign dominance to assist domestic producers in achieving high quality, efficient production processes. The expansion of domestic production of the increasingly vital GaAs wafers will assure continued availability for U.S. defense systems and will eventually lead to a viable U.S. commercial production base.

## Status

*Active*
*Start date: March 1994*
*End date: February 1998*

## Resources

*Project Engineer:*
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*AFRL/MLMP*
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*Title III Funded*

*Contractors:*
*American XTAL Technology*

*Airtron Division of Litton Corporation*

*M/A-COM, Inc.*

# Semi-Insulating (SI) Indium Phosphide (InP) Wafers



**Contract Numbers: F33733-97-C-1022/1023 ALOG Numbers: 1502/1549**

## Statement of Need

The objective of this project is to establish viable, long-term, world-class manufacturing capabilities for Indium Phosphide (InP). InP is a compound semiconductor material that is critical to a variety of optoelectronic and very high-frequency, millimeter wave, and high-power microwave electronics. DoD is investing heavily in the development of InP-based devices; however, the manufacturing infrastructure for InP wafers production is not capable of meeting DoD requirements with respect to quality, price, size and availability. Increased domestic production capacity for InP is required to support current and future needs for both military and commercial applications. Systems requiring InP include the following: BAT, BCIS, MILSTAR, GPS, MILSATCOM, GBR, F-22 and F-15. The unique properties of InP cause it to be an enabling technology. Unlike silicon, InP is intrinsically resistant to radiation. Important uses of InP are in the fabrication of heterojunction bipolar transistors (HBTs) and high-electron mobility transistors (HEMTs) for analog, digital and optoelectronic devices. Title III incentives will be used to enable transition to full-scale manufacturing, improve affordability and quality, target military systems insertions, and leverage government investments.

## Approach

Each of the two contracts is a single-phased effort aimed at establishing an economically viable production capability for semi-insulating indium phosphide wafers. The effort consists of eight tasks which include aggressive marketing and business development, optimizations of crystal and wafer (75mm) growth processes, cost reduction, production scaleup, material qualification and wafer distribution. Also included is the demonstration of 100mm wafer production.

## Benefits

Specific benefits and gains expected to be achieved by the project are: improved 75mm wafer quality (uniformity, consistency, surface preparation, defect reduction); increased 75mm boule/wafer yield; cost reductions of 50 percent; the establishment of partnerships for material evaluation/qualification; and demonstration of production capability for this enabling technology. The project also seeks to provide wafers to government, industry, and universities for materials characterization which is expected to lead to a greater understanding and insertion of this material in electronic systems. The overall benefit expected from the project is a clear path for each contractor to follow in achieving business viability in the production of InP wafers for commercial and military use.

## Status

*Active*
*Start date: May 1997*
*End date: January 2000*

## Resources

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